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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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REGULATORY POLICIES AND PRACTICES SUBCOMMITTEE

+ + + + +

THURSDAY

AUGUST 18, 2011

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear
Regulatory Commission, Two White Flint North, Room
T2B3, 11545 Rockville Pike, at 1:00 p.m., William
Shack, Chairman, presiding.

SUBCOMMITTEE MEMBERS PRESENT:

WILLIAM J. SHACK, Chairman

DENNIS C. BLEY

CHARLES H. BROWN, JR.

JOHN W. STETKAR

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NRC STAFF PRESENT:

GIRIJA SHUKLA, Designated Federal Official

SELIM SANCAKTAR

BRAD HARVEY

MILTON BALLENTINE

ALSO PRESENT:

EMIL SIMIU

PETER VICKERY

I-N-D-E-X

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PAGE

Opening Remarks and Objectives

by Bill Shack

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Regulatory Basis. History of Extreme Wind

Regulatory Guidance

by Brad Harvey

6

Draft final Regulatory Guide (RG) 1.221

"Design Basis Hurricane and Hurricane

Missiles for Nuclear Power Plants."

by Selim Sancaktar

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P-R-O-C-E-E-D-I-N-G-S

1:00 p.m.

CHAIR SHACK: The meeting will now come to order. This is a meeting of the Advisory Committee on Reactor Safeguard Subcommittee of Reactor Policies and Practices. I am Bill Shack, Chairman of the Subcommittee.

Subcommittee members in attendance are John Stetkar, Charles Brown and Dennis Bley. Mr. Girija Shukla of NRC Staff is the designated Federal Official for this meeting.

The Subcommittee will hear presentations from the NRC Staff regarding the new Staff Guidance for use in selecting the design basis hurricane wind speed and hurricane generated missiles that a new nuclear power plant should be designed to withstand, as discussed in the draft Reg Guide 1.221, Design Basis Hurricane and Hurricane Missiles for Nuclear Power Plants.

We have received no written comments or requests for time to make oral statements from members of the public regarding today's meeting. The meeting will be open to public attendance.

The Subcommittee will gather information, analyze relevant issues and facts and formulate

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1 proposed positions and actions, as appropriate, for
2 deliberation by the full committee.

3 The rules for participation in today's
4 meeting have been announced as part of the notice of
5 this meeting published in the Federal Register on July
6 25th, 2011. A transcript of the meeting is being kept
7 and will be made available as stated in the Federal
8 Register notice.

9 Therefore, we request that participants in
10 this meeting use the microphones located throughout
11 the meeting room when addressing the Subcommittee.
12 The participants should first identify themselves and
13 speak with sufficient clarity and volume so they may
14 be readily heard.

15 Please silence your cell phones if you
16 have them. We will now proceed with the meeting. And
17 I call upon Selim Sancaktar of the NRC staff to make
18 introductory remarks.

19 MR. SANCAKTAR: Thank you. My name is
20 Selim Sancaktar. I work for the NRC in Office of
21 Research. We are here to provide a presentation on
22 impending Regulatory Guide 1.221, on Design Basis
23 Hurricane and Hurricane Missiles for Nuclear Power
24 Plants.

25 I will quickly pass it on to one our major

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1 presenters, Brad Harvey, from the Office of New
2 Reactors. Besides myself there are three presenters
3 here and they are, in my opinion, are very good
4 representatives of their respective fields and I hope
5 that you will receive useful and satisfactory
6 information from each of them.

7 So with this I will pass to Brad. And I
8 think we'll shift your way.

9 MR. HARVEY: Good afternoon. My name is
10 Brad Harvey. And I am a Senior Physical Scientist in
11 the Division of Site Environmental Reviews within the
12 Office of New Reactors. I was responsible for
13 initiating a user's need that resulted in development
14 in Reg Guide 1.221.

15 This slide outlines my presentation. I
16 plan to review the regulatory basis for Reg Guide
17 1.221 and describe the history of NRC's Extreme Wind
18 Regulatory Guidance. Including explaining the Design
19 Basis Wind Law Criteria and presenting the basis of
20 the Design Basis Tornado Wind Speeds.

21 The intent of this presentation is two-
22 fold. One, to describe the basis for defining the
23 Design Basis Tornado Wind Speeds and the Design Basis
24 Hurricane Wind Speeds as corresponding to an
25 exceedance frequency of 10^{-7} per year.

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1 And two, to explain why the design basis
2 tornado maximum wind speeds have decreased over time
3 to the point that it was no longer clear that the
4 revised design basis tornado wind speeds would bound
5 corresponding hurricane wind speeds in all areas of
6 the United States.

7 One of the regulatory criteria that
8 establishes the requirements for the design basis
9 tornado and hurricane can be found in Appendix A to 10
10 CFR, Part 50. General design criteria for nuclear
11 power plants.

12 In particular GDC 2 says, structures
13 systems and components important to safety shall be
14 designed to withstand the effects of natural
15 phenomenon such as tornados, hurricanes while at loss
16 of capacity to perform the safety functions.

17 The design basis for SSCs shall reflect
18 appropriate consideration of the most severe of the
19 natural phenomenon that have been historically
20 reported for the site and surrounding area. With
21 sufficient margin for the limited accuracy, quantity
22 and period of time in which the historic data have
23 been accumulated.

24 Another regulatory criteria now
25 establishes the requirement for design basis tornado

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1 and hurricane can be found in Subpart B, which is the
2 evaluation factors for stationary power reactor site
3 applications, to Part 100 citing criteria.

4 In particular, 10 CRF 100.20(c)(2) says
5 meteorological characteristics of the site that are
6 necessary for safety analysis or that may have an
7 impact upon plant design, such as maximum probably
8 wind speed and precipitation, must be identified and
9 characterized.

10 10 CRF 100.21(d) further states that the
11 physical characteristics of the site, including
12 meteorology, must be evaluated and site parameters
13 established such that potential threats from such
14 physical characteristics will pose no undue risks to
15 the type of facility proposed to be located at the
16 site.

17 The U.S. NRC Regulatory Guide suggests two
18 design points for wind loads, as shown in this table.
19 For example, Reg Guide 1.142, which describes
20 acceptable methods for the design of safely-related
21 concrete structures, states that the procedures and
22 requirements described in American Concrete Institute
23 Standard, ACI 349-97 are generally acceptable to the
24 staff.

25 As a result the guides in ACI 349-97, as

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1 well as guides presented in several SRP sections, such
2 as 2.3.1 and 3.8.4, form the basis for this table.

3 The first design point is commonly called the
4 operating basis window which represents a severe
5 environmental load that could infrequently be
6 encountered during the life of the plant.

7 ACI 349-97 and SRP 2.3.1 define the
8 operating basis wind as wind velocities and forces
9 associated with 100-year recurrence interval or an
10 exceedance frequency of 10^{-7} per year. SRP 3.3.1
11 describes the procedures that should be used to
12 transform the operating basis wind load into an
13 equivalent pressure.

14 The second design point is commonly called
15 the design basis tornado, which represents an extreme
16 environmental load that is credible but highly
17 improbable. Reg Guide 1.76 defines the design basis
18 tornado as corresponding to an exceedance frequency of
19 10^{-7} per year calculated as a best estimate.

20 SRP 3.3.2 describes procedures that should
21 be used to transform design basis tornado
22 parameters into effective loads. As shown in the last
23 column in this table the operating basis window, in a
24 design basis tornado load, are used with different
25 load factors and load combinations. In ACI 349-97 to

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1 evaluate the capacity of concrete structures to
2 withstand wind pressures.

3 For example the operating wind basis W has
4 a load factor of 1.7, here, which in part accounts for
5 the probability that wind speeds higher than the
6 operating basis wind load might occur during a plant's
7 life. No such factor appears for design basis tornado
8 load, down here.

9 Note that Reg on 1.221 is intended to
10 represent hurricane loads that represent an extreme
11 environmental load that is credible but highly
12 improbable. Similar to that of a design basis tornado
13 with an exceedance of 10^{-7} per year.

14 MEMBER STETKAR: Brad, I don't want to
15 dwell on this too much. But the notion of credible
16 but highly improbable, can you explain the notion of
17 credibility to events that you claim you understand
18 with a frequency of once in ten million years?

19 MR. HARVEY: I think that for the purposes
20 of my factor. If you look at ACI 349-97 --

21 MEMBER STETKAR: No. I'm asking you. Can
22 you explain the notion of the, not ACI, not the Reg
23 Guide, can you explain your understanding as an
24 NRC/NRO manager.

25 Of what can be credible when you're trying

1 to say we understand that at a exceedance frequency of
2 once in ten million years. Given the age of the Earth
3 and the age of recorded history on the Earth and the
4 range of variability in extreme meteorological events?

5 Is there any notion of credibility to
6 those known loads?

7 MR. HARVEY: Credible may not be the right
8 word here. Highly improbable is probably the word.

9 MEMBER STETKAR: Well, I'd highly grant
10 you that highly improbable is 10 to the ninth, I'd
11 also grant you that once in 10,000 years is highly
12 improbable. Maybe even once in 1,000 years is highly
13 improbable to a lot of people.

14 MR. HARVEY: But when it comes to tornados
15 though, it is possible that some place in the United
16 States we have seen tornados that have the wind speeds
17 that we're discussing.

18 MEMBER STETKAR: Absolutely, that's
19 correct. There's strong variability, I'm not --

20 MR. HARVEY: So in that point --

21 MEMBER STETKAR: But we have seen those.

22 MR. HARVEY: But that's why they're
23 credible.

24 MEMBER STETKAR: Right. Exactly, I'm not
25 arguing about the credibility of the things that we've

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1 seen or are slightly larger than things that we've
2 seen.

3 MR. SIMIU: Could I?

4 MEMBER STETKAR: Sure.

5 MR. SIMIU: It is true that we don't have
6 many data sets of size ten million or larger.

7 MEMBER STETKAR: Show me the one, I'd
8 really like to see it.

9 MR. SIMIU: Well, I was joking. But we do
10 have estimation methods that have a certain
11 credibility and have been tested for many recurrence
12 intervals that are --

13 MEMBER STETKAR: So we've looked at
14 several ten million year snapshots of the Earth's
15 history and have that information.

16 MR. SIMIU: No, we looked at various
17 snapshots where we had, for example, 30 years of data
18 and could make credible extrapolations to 1,000 to
19 10,000 years, which can be verified.

20 Even though we don't have, at a particular
21 location, a 10,000 year site. We do have many
22 locations and if we pool those data we can make some
23 inferences to a larger mean recurrence interval that
24 are credible.

25 That establishes, to some extent, the

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1 credibility of the methodologies that I used to make
2 inferences for larger mean recurrence intervals than
3 those that have been experienced in a lifetime or two
4 lifetimes.

5 So credibility pertains to the estimation
6 methods that is applied to a large number of data
7 sets. That is one way to address your very legitimate
8 question.

9 MEMBER STETKAR: Well also I note that in
10 your examples you said we can use information perhaps
11 compiled over decades to maybe a couple hundred years
12 to have some confidence in extrapolating out to, I
13 think you used 1,000 years or 10,000 years.

14 That's one degree of extrapolation and
15 some amount of uncertainty. Extrapolating yet another
16 factor of 1,000 beyond that to ten million years is a
17 daunting challenge.

18 MR. SIMIU: It is. And it is a challenge
19 that needs to be addressed.

20 (Simultaneous speaking)

21 MEMBER STETKAR: The question is why does
22 it need to be addressed? Why does this arbitrary 10^7
23 that we are expending a lot of effort on, what's the
24 basis for that number? Why is it not 10^{-4} or
25 something that we can --

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1 MR. HARVEY: My presentation goes into
2 that a little bit. It's basically it's part of a
3 second paper that we provided to the commission which
4 it responds, we affirm, 10^{-7} .

5 MEMBER STETKAR: Well, sure. Seven's only
6 like five more than two. So it's not a big abyss.

7 MR. HARVEY: The way I look at it, it's a
8 highly improbable event. So you're right, it's very
9 hard with any sort of perceived accuracy whatsoever to
10 calculate that.

11 MEMBER STETKAR: That's the key.

12 MR. HARVEY: But my point --

13 MEMBER STETKAR: Are we making regulatory
14 decisions based on a perceived degree of confidence or
15 credibility in numbers that perhaps have very little,
16 if any, basis for that perceived degree of confidence
17 or credibility?

18 In other words should we be making
19 regulatory decisions based on numbers that we have a
20 higher degree of confidence in, perhaps one in 1,000
21 or one in 10,000 years if you'll allow me that, that
22 might have higher wind speeds and perhaps somebody
23 would have to deal with that.

24 MR. SIMIU: Well we already have --

25 MEMBER STETKAR: I'm sorry lower wind

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1 speeds. Lower wind speeds.

2 MR. SIMIU: We already have done that for
3 the building we're in, for example. We don't want it
4 to collapse every ten years. We have 1,000 to 10,000
5 even 100,000 years. When you consider, which is
6 another way of saying that we have a probability of
7 failure that is perceived as sufficiently low.

8 And we would like nuclear power plants to
9 be safer even than this building that we don't want to
10 collapse, because we're in it. But the consequences
11 will be so great that we take additional work.

12 CHAIR SHACK: John, this is really, the
13 newest metrics for new reactors kind of stuff.

14 MEMBER STETKAR: No, I understand that.
15 But it's also something that's being published in the
16 year 2012 that may not be updated for another 30 or 40
17 years given the recurrence interval of updating
18 regulations.

19 CHAIR SHACK: I think it will take a
20 policy, a second --

21 MR. HARVEY: The second paper that we
22 presented the Commission with alternatives reducing
23 the frequency and they didn't buy into it. Hence, I'm
24 following, it's a policy decision the Commissioners
25 made in 2004 and I feel compelled to live to it.

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1 SRP 3.3.2, which is entitled Tornado
2 Loads, is concerned with the design of structures that
3 must withstand the effects of design basis tornado.
4 SRP 3.3.2 states that tornado effects can be divided
5 into three groups. One, tornado effects caused by the
6 direct action of airflow on structures.

7 Two, atmospheric pressure changes effects
8 caused by differential pressure between the interior
9 and exterior of a structure during the passes of a
10 tornado.

11 And three, tornado generated missiles.
12 Tornado effects considered in design should include
13 combinations of tornado wind effects, atmospheric
14 pressure change effects and tornado generated missile
15 impact effects.

16 This slide shows acceptable methods for
17 combining these effects and establishing the total
18 tornado load on a structure, as specified in SRP
19 3.3.2.

20 MEMBER BROWN: Can you go back?

21 MR. HARVEY: Sure.

22 MEMBER BROWN: You have two equations?

23 MR. HARVEY: Yes.

24 MEMBER BROWN: I'm not a statistician or
25 number cruncher like this. But I've W_t and W_p and

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1 then I've got the same thing as a bunch of other
2 factors. You're giving them two conditions that they
3 have to consider? They can either do one or the
4 other? They can either consider pressure and not
5 exclude the wind load and the missile impact?

6 MR. HARVEY: My understanding is they
7 would evaluate both of these and take the more
8 conservative of the two as the design basis.

9 MEMBER BROWN: So it's a combinational
10 issue? I mean that's what, if you use one effect et
11 all, but if that's more conservative than the other
12 one where you put a factor in front of it. And then
13 the other ones don't have to overwhelm that other half
14 in order to become more conservative, is that?

15 MR. HARVEY: I think that's correct.

16 MEMBER BROWN: So the wind effects and the
17 missile effects have less impact than the atmospheric
18 pressure change? It's the pressure changes that do
19 most of the destruction in a tornado? The pulses?

20 MR. VICKERY: It depends on the building.

21 MR. HARVEY: And they don't occur at that
22 same time.

23 MEMBER BROWN: Well I know missiles and
24 the other things don't necessarily occur at the same
25 time.

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1 MR. VICKERY: Neither does the pressure
2 change and the wind. If a building is very, very
3 leaky then the pressure change doesn't really play a
4 role at all. If the building is sealed then the
5 pressure --

6 MR. HARVEY: Yes, I understand that point.
7 All right, go ahead. I'm just trying to wrap myself
8 around two different equations applying for this, and
9 how do you pick. I mean do you choose leaky buildings
10 or non-leaky buildings?

11 MR. HARVEY: Well I think it depends on
12 the building. Some buildings are like this, they're
13 intended to leak a bit. So you'll see that one of the
14 design basis tornado criteria is the pressure rate.

15 Or the rate of increase and decrease of
16 pressure. And so you can show that the building can
17 adjust to that, almost instantaneously, so you can
18 make the pressure term go away.

19 MR. BALLENTINE: Excuse me. My name is
20 Milton Ballentine, and I work for the Structural
21 Engineering Branch and we have gone thoroughly over
22 SRP 3.3.2, and just to support what Brad said. We
23 consider both the differential pressure and the
24 combination of the wind speed plus the missiles and we
25 have the most conservative case to take into

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1 consideration. So we look at both.

2 MEMBER BROWN: But you might have
3 circumstances where the other two are zero and all you
4 have to do is consider atmospheric pressure?

5 CHAIR SHACK: You just pick the one that's
6 controlling. I mean you have a structure that sort of
7 deals with both, but you design to the controlling
8 one.

9 MR. BALLENTINE: Exactly.

10 MEMBER BROWN: I just kind of had a hard
11 time seeing the differential pressure changes being
12 based on observing what you see in some of these great
13 videos of tornados ripping through stuff and the
14 missile impact, which is really cramming, you know,
15 really destroys stuff when it hits this.

16 It being less of an effect than the
17 atmospheric pressure, but I'll, since I'm not an
18 expert on this I'll --

19 (Off microphone discussion)

20 MEMBER BROWN: No, there have been videos
21 of the houses blowing apart from the pressure changes
22 as well. Go ahead, I'm just trying to learn something
23 here.

24 MR. HARVEY: The staff's definition of an
25 extreme environmental wind load has been evolving

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1 during the last several decades. Until Reg Guide
2 1.221, the staff's definition of extreme environmental
3 wind load has been based on the definition of a design
4 basis tornado. Because tornado loads are assumed to
5 be the bounding wind for all meteorological
6 phenomenon.

7 The design basis tornado was first defined
8 in the original version of Reg Guide 1.76 in April of
9 1974. The definition of design basis tornado was
10 revised in March 1988 with the issuance of a staff
11 internal position based on additional historic tornado
12 data that was available at that time.

13 The staff revised this definition of
14 design basis tornado again in April of 1993 by stating
15 in SECY 93-87 that the design basis tornado should
16 have mean recurrence 10^{-7} per year instead of 10^{-7} for
17 probability of occurrence at the upper 90 percent
18 confidence interval level.

19 In October 2004, SECY 04-200 confirmed
20 that the design basis tornado should have a mean
21 recurrence interval 10^{-7} per year and committed to
22 updating Reg Guide 1.76 to reflect more recent tornado
23 wind speed data that were available. The draft
24 revision of Reg Guide 1.76, DG-1143, was distributed
25 for public comment in February of 2006.

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1 And the final Revision 1 to Reg Guide 1.76
2 was issued approximately a year later in March 2007.
3 With the issuance of Draft Reg Guide 1.221, or DG-1247
4 in August 2010, the staff is proposing for the first
5 time to expand its definition of the extreme
6 environmental wind load to include hurricanes.

7 Because variable data were available when
8 the original version of Reg Guide 1.76 was written in
9 1974, generalized conservative estimates were utilized
10 in the development of the original design basis
11 tornado.

12 Since then the National Severe Storms
13 Forecast Center, which is now known as the Storm
14 Prediction Center, has developed a tornado database
15 which provides information on the intensity and damage
16 area of tornados which have occurred in the United
17 States since 1950.

18 The staff has revised its design basis
19 tornado over time using the information compiled in
20 this database, along with more sophisticated data
21 analysis techniques. As a result the maximum wind
22 speeds associated with the design basis tornado have
23 decreased from 360 miles per hour in 1974 to 230 miles
24 per hour in 2007.

25 We will explore the reasons for this trend

1 in the following slides. Okay my understanding is you
2 prefer to skip over.

3 CHAIR SHACK: Yes, I think that we can
4 come back to this if we have time today.

5 MR. HARVEY: That's just how the tornado
6 model works. What I do want to point out, and briefly
7 describe is the Fajita Tornado Scale, or F-Scale.
8 Direct measurements of wind speeds in a tornado are
9 rare because tornados only exist for short periods of
10 time at random places. And they have a tendency to
11 destroy local measurement equipment.

12 The F-Scale was induced in 1971 as a
13 method for rating tornado intensity based on observing
14 the damage inflicted on human built structures and
15 vegetation. The F-Scale for a tornado is determined
16 after performing a ground and/or aerial survey of the
17 damage caused by a tornado.

18 Qualitative descriptions of the observed
19 damage are then used to classify the tornado. The
20 staff's first guidance on design basis tornados are
21 provided in the original version of Reg Guide 1.76
22 which was issued in April 1974.

23 Design basis tornado specified in Reg
24 Guide 1.76 were based on assumptions and mathematical
25 models and in 1974 document WASH-1300, Technical Basis

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1 for Interim Regional Tornado Criteria.

2 WASH-1300 selected its maximum design
3 basis tornado wind speeds on the premise that the
4 probability of occurrence of a tornado that exceeds a
5 design basis tornado should be on the order of 10^{-7}
6 per year per nuclear power plant.

7 The staff calculated the expected
8 frequency of different tornado wind speeds for the
9 three different regions in the continental United
10 States using 13 years of regional tornado frequency
11 data, 1955 to 1967.

12 And two years of tornado intensity data,
13 1971 through 1972, based on the newly defined Fajita
14 Tornado Scale, or F-Scale. This slide shows the
15 resulting Reg Guide 1.76 design basis tornado for
16 three regions within the contiguous United States.

17 Reg Guide 1.76 concluded that a maximum
18 speed of 360 miles per hour should be consistent with
19 a 10^{-7} per year probability of occurrence for much of
20 the United States east of the Rocky Mountains.

21 Model wind speeds of 300 miles per hour
22 and 240 miles an hour were appropriate for regions
23 west of the Rocky Mountains, which are Regions 2 and
24 3.

25 The Regulatory Guide specified the nuclear

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1 plant should be designed to withstand the design basis
2 tornado for each region or comprehensive analysis be
3 provided to justify the selection of a less
4 conservative design basis tornado.

5 In March 1988 the staff issued an interim
6 position on the design basis tornado based on the
7 analysis presented in NUREG/CR-4461, which is the
8 Tornado Climatology of the Contiguous United States,
9 which was dated in May 1986.

10 NUREG/CR-4461 recalculated tornado wind
11 speed frequencies using a significantly improved
12 tornado database containing 30 years of data, 1954
13 through 1983.

14 The resulting wind speed estimates were
15 lower than the wind speed estimates presented in WASH-
16 1300, Regulatory Guide 1.76, for most of the United
17 States.

18 To account for uncertainties in the
19 database and analysis, the staff included in its
20 interim position that the 10^{-7} per year probability of
21 current wind speed at the upper level of the middle 90
22 percent confident level of NUREG/CR-4461 should be
23 used as the wind speed for the design basis tornado.

24 On this basis the staff interim position
25 recommended a maximum wind speed of 330 miles per hour

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1 for Region 1. Again, this shows the resulting staff
2 interim design basis tornado for four regions within
3 the contiguous United States.

4 SECY 93-087 was prepared by the staff in
5 April 1993 to present the Commission with recommended
6 positions pertaining to evolutionary and passive
7 light-water reactor designed certification policy
8 issues.

9 The staff recommended in SECY 93-087 that
10 a 10^{-7} per year mean probability of occurrence,
11 instead of the more conservative upper 90 percent
12 confidence level presented in the staff interim
13 position, should be used as a basis for the certified
14 standardized tornado wind speed.

15 Based on the analysis in presented in
16 NUREG-4461 the wind speeds associated with a tornado
17 having a mean recurrence interval 10^{-7} per year were
18 estimated to be about 300 miles per hour east of the
19 Rocky Mountains and 200 miles per hour west of the
20 Rocky Mountains.

21 Therefore, the staff recommended that a
22 maximum tornado wind speed of 300 miles per hour be
23 used in a design basis tornado employed in the design
24 of the evolutionary and passive advanced light water
25 reactors. SECY 93-087 also stated that the staff

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1 expected that this criterion would not preclude citing
2 the advanced light water reactor plant designs on most
3 sites in the United States.

4 Furthermore, if a tornado has, at a
5 selected site, exceeded the approved certified
6 standardized design envelope the COL Applicant would
7 have the option of performing a site-specific analysis
8 to demonstrate the design is acceptable for the site.

9 December 2003 the staff sought Commission
10 approval, via SECY 03-227, to issue Review Standard
11 RS-002 for processing applications for early site
12 permits. The guidance in RS-002 called for the use of
13 the following for selecting site specific tornado
14 parameters.

15 One, Regulatory Guide 1.76, which specify
16 a maximum wind speed of 360 miles an hour for much of
17 the United States east of the Rocky Mountains.

18 Two, a staff interim position which
19 specified a maximum wind speed of 330 miles and hour
20 for much of the United States east of the Rocky
21 Mountains.

22 Or three, a site-specific analysis to
23 justify a different wind speed. In the process of --

24 CHAIR SHACK: You didn't really expect
25 anybody to pick 1.76 did you?

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1 MR. HARVEY: Probably not, no. But that's
2 what the guidance said. In the process of approving
3 RS-002 the Commission expressed concerns regarding an
4 apparent inconsistency between the maximum tornado
5 wind speeds assumed for the certified standard reactor
6 designs, which is 300 miles an hour. As discussed at
7 SECY 93-087.

8 And the guidance related to tornado wind
9 speeds in RS-002 that would be applied to sites that
10 might host these new reactor designs. In order to
11 address this inconsistency the Commission directed the
12 staff to, one, update its regulatory guidance
13 including Reg Guide 1.76 to reflect more recent
14 tornado wind speed data that are available.

15 And two, develop options in applying a
16 risk informed approach to the selection of a design
17 basis tornado. In response to this directive, the
18 staff again updated NUREG/CR-4461 and issued SECY 04-
19 200 in October 2004.

20 Providing the Commission with three
21 options for applying a risk informed approach to the
22 selection of design basis tornado.

23 These options were. Option one, maintain
24 the current SECY-93-087 definition of design basis
25 tornado as a tornado having a mean frequency of 10^{-7}

1 per year. This option was based, in part on
2 preliminary results from advice in NUREG/CR-4461 that
3 indicated that the updated maximum wind speeds for
4 tornados having a mean frequency of 10^{-7} per year
5 would be on the order of 300 miles an hour.

6 Option two, develop a risk informed
7 alternative approach that would permit the use of a
8 less conservative design basis tornado of higher
9 frequency, that is lower maximum wind speed by a
10 higher probability that a maximum could be exceeded.

11 This approach would permit a design basis
12 tornado of higher mean frequency than 10^{-7} per year if
13 a risk analysis satisfactorily demonstrates that the
14 risk from tornado strikes with frequencies between the
15 selected design basis frequency, at 10^{-7} per year, was
16 sufficiently small.

17 The third options was to relax the
18 definition of design basis tornado to initiating
19 frequency of less than 10^{-7} per year, i.e. closer to
20 10^{-6} per year, in order to be consistent with the
21 definition of well advanced, adjusted and recent risk
22 informed regulatory guidance.

23 In the response to SECY 04-200, the
24 Commission approved Option 1 because the
25 inconsistencies in NRC regulatory guidance documents

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1 concerning the design basis tornado parameters were
2 expected to be resolved with the update NUREG/CR-4461.

3 This meant that the definition of the
4 design basis tornado as having a tornado having a mean
5 frequency of 10^{-7} per year was being maintained.

6 Revision one to NUREG/CR-4461 was
7 completed in April 2005, and its results were used to
8 generate a Draft Revision 1 to Reg Guide 1.76, DG-
9 1143, in January 2006. The tornado database used in
10 revised CR-4461 included information recorded from
11 January 1950 through August 2003.

12 The methods used in revising the analysis
13 were similar to those using analysis of previous
14 tornado climatology and that results in the initial
15 publication NUREG/CR-4461 in 1986, except for, one, a
16 term was added to account for the finite dimensions of
17 structures whereas the original NUREG/CR-4461 assumed
18 the power plant was a point structure.

19 And two, the valuation of wind speeds
20 along and across the tornado footprint were accounted
21 for, whereas the original NUREG/CR-4461 did not
22 account for the variation of the intensities along the
23 tornado path.

24 The results of this study, which are shown
25 in the next slide, indicated that maximum wind speed

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1 of 300 miles an hour is appropriate for tornados for
2 the central portion of the United States.

3 A maximum wind speed of 260 miles per hour
4 is appropriate for the western portion of the Great
5 Plains and for the east coast. And a maximum wind
6 speed of 200 mile and hour is appropriate for the
7 western United States.

8 With the publishing of DG-1143, the staff
9 decided the new design basis missile spectrum from SRP
10 3.5.1.4 into DG-1143. The selected design basis
11 missile spectrum for nuclear power plants included,
12 one, a massive high-kinetic energy missile that
13 deforms on impact.

14 Two, a rigid missile that tests
15 penetration resistance. And three, a small rigid
16 missile of sufficient size that pass through any
17 openings or protected barriers.

18 The staff determined that a six inch
19 schedule 40 steel pipe and an automobile are
20 acceptable as a penetrating and massive missiles,
21 respectively, for use in a design of nuclear power
22 plants as common objects near the plant's site.

23 In order to test the configuration
24 openings in the protected barriers, the missile
25 spectrum also included a one inch solid steel sphere

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1 as a small, rigid missile. The table on this slide
2 shows the resulting missile speeds.

3 These missiles were derived by solving the
4 equations in motion for a missile imbedded in a
5 tornado wind speed. Resulting are the missile maximum
6 horizontal speeds were approximately 45 to 40 percent
7 of the maximum tornado speeds for each region.

8 The maximum speed calculated for the pipe
9 and spear missiles were somewhat less. Especially for
10 the lower wind speeds in tornado Regions 2 and 3. The
11 missile vertical velocities were assumed to be two-
12 thirds of the missile horizontal velocities.

13 As discussed previously, the F-Scale has
14 been used to rate tornado intensity based on the
15 amount of damage created by the tornado. The original
16 F-Scale was introduced in 1971.

17 Little information was available that time
18 on damage caused by wind, so the original F-Scale
19 represented little more than educated guesses at wind
20 speed ranges for specific tiers of damage.

21 The Enhanced Fajita Scale, or EF-Scale was
22 subsequently formulated as a result of research which
23 suggested that the wind speeds required to inflict
24 damage by intense tornados on the F-Scale were greatly
25 overestimated. A process of expert elicitation among

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1 structural engineers and meteorologists resulted in
2 the EF-Scale.

3 The new EF-Scale was publicly unveiled by
4 the National Weather Service on the same day that DG-
5 1143 was issued for public comment, which was February
6 2nd in 2006. It began operational use on February
7 1st, 2007. As for the F-Scale, the EF-Scale is a
8 damage scale and only a proxy for actual wind speeds.

9 The major difference between the two
10 scales is the adjusted wind speeds. For example, the
11 old F-Scale listed F4 tornados as having a three-
12 second gust wind speeds between 210 and 261 miles per
13 hour.

14 The new EF-Scale found that the three-
15 second gust wind speeds between 166 and 200 miles an
16 hour were sufficient to cause the damage previously
17 ascribed to the F4 range of wind speeds.

18 MEMBER STETKAR: So now we understand that
19 lower wind speeds cause the same damage that we
20 thought was caused by higher wind speeds in the past?

21 MR. HARVEY: That's correct.

22 MEMBER STETKAR: Thanks.

23 MR. HARVEY: Go ahead.

24 MEMBER BLEY: Yes, because I wasn't around
25 to follow that stuff as it was done. Both scales were

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1 based on expert judgement --

2 MR. HARVEY: On the damage.

3 MEMBER BLEY: On the damage.

4 MR. HARVEY: The SR was probably a little
5 bit less expert.

6 MEMBER BLEY: What kind of thing did we
7 learn that meant the second experts be, we hope,
8 better than the first? Did we have much actual
9 instrumentation in any of these? Do we have any real
10 measurements that help support it? Was it
11 calculations, wind tunnel --

12 MR. HARVEY: I think it was calculation on
13 wind tunnel tests.

14 MR. SIMIU: Yes, it's also that Fajita was
15 a meteorologist and had very limited structural
16 engineering experience. In time structural engineers
17 tried to back calculate the loads that would cause
18 certain degrees of damage.

19 And they concluded that Enhanced Fajita
20 Scale was more appropriate than the strictly
21 subjective and, I wouldn't say uneducated, but
22 subjective estimates by a meteorologist of what the
23 structural resistance of certain buildings would be
24 under loading.

25 MEMBER BLEY: I'm just curious, because

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1 like I say, I didn't follow it. Is there a large body
2 of calculations, a large broad expertise in this area
3 that led to this. Is it a consulting firm or two that
4 did the calculations and put this all together?

5 MR. SIMIU: I think that, yes Larry was
6 involved.

7 MR. VICKERY: Yes, sort of. Larry
8 Twisdale was involved but he got fed up and left.

9 (Simultaneous speaking)

10 MR. SIMIU: It was the Texas Tech.

11 MR. VICKERY: In my opinion it was too
12 low, but that's just my opinion.

13 MR. SIMIU: Texas Tech.

14 MEMBER BROWN: You mean you think the wind
15 speeds are too low?

16 MR. VICKERY: Yes, but it's just my
17 personal opinions.

18 MEMBER BLEY: So you think it's the
19 reverse of what --

20 MR. VICKERY: No.

21 MEMBER BLEY: You think it should go even
22 further than it's gone?

23 MR. VICKERY: No. I think if they went
24 from 117, well, that's a bad example. Going from 209
25 to 165, it's probably higher than 165, that's all.

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1 But it sure isn't 209.

2 MEMBER BLEY: Okay.

3 MEMBER BROWN: So you think they adjusted
4 too much?

5 MR. VICKERY: I think, my personal
6 opinion, based on our calculations for the hurricanes
7 is it's a little bit too low, but it's judgement.

8 MR. SIMIU: You're not a structure
9 engineer yourself.

10 MR. VICKERY: Yes, that's an advantage in
11 some cases. I do make calculations.

12 MEMBER STETKAR: You know in the last
13 decade or so there's been a lot more measurements of
14 tornados. I mean it's become kind of a fad to go out
15 and try to measure things. And one can argue about
16 how reliable some of those measurements are.

17 But tornados are not particularly rare
18 events around the country. And there are people who
19 fanatically follow those things and try to measure
20 wind speeds and --

21 MR. VICKERY: But not at ten meters.

22 MEMBER STETKAR: Not at ten meters, no.

23 MR. VICKERY: And that's the problem.

24 MEMBER STETKAR: That is true, that is a
25 problem. But at least at ground level I think we have

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1 better data than we had 30/40 years ago.

2 MR. VICKERY: Yes --

3 MEMBER BLEY: I want to go a little
4 further in understanding how this develops. We've got
5 the EF numbers now that I assume correspond to the
6 same kind of, I mean on your earlier slide you showed
7 us the F-Scale and showed photographs, so I guess a
8 person could say, gee, well we had about that much
9 damage so that's an F3.

10 Do we have, you know, are we using the
11 same set of six photographs for --

12 MEMBER BROWN: No.

13 MEMBER BLEY: What are we using these days
14 and who we thought -- like most, I assume most tornado
15 don't hit anything so you can't use, most of them you
16 use the ones that hit stuff that --

17 MR. HARVEY: There's like a set of 28
18 different criteria you that you look at. You look at
19 the structure itself, whether or not it's a
20 residential house or a commercial grade building.

21 MEMBER BLEY: So there's descriptive
22 criteria of what would have happened --

23 MR. HARVEY: Yes, much more so than just
24 pictures. And it's a quantum leap forward from the F-
25 Scale to the EF-Scale.

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1 MEMBER BLEY: There's an agency that
2 actually goes out and tracks these or is it --

3 MR. HARVEY: The National Weather Service
4 actually every --

5 MR. VICKERY: The folks in Oklahoma make
6 the final discernment, determination.

7 MR. HARVEY: Yes, they do. The experts
8 will go out there and they look at the damage and they
9 characterize the intensity the length and the width of
10 the tornado.

11 MEMBER BLEY: Then they do that based on
12 the EF-Scale now and these criteria?

13 MR. HARVEY: Correct.

14 MR. VICKERY: Yes.

15 MR. SIMIU: And they take into account the
16 type of code on which a structure was designed. And
17 I will add it's a very imperfect system still. It's
18 the best one could do so far.

19 MR. VICKERY: Yes, it's certainly better
20 than what they had before and they had a lot of
21 opinion.

22 MEMBER BLEY: I just needed some basic
23 background. Go ahead.

24 MR. HARVEY: Okay. Because the design
25 basis wind and draft Revision 1 to Reg Guide to 1.76,

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1 or DG-1143, were developed using the F-Scales. And
2 the National Weather Service began implementing the
3 EF-Scale in February 2007 its second revision to
4 NUREG/CR-4461 was developed which recalculated design
5 basis tornado wind speeds using wind speed estimates
6 based on the EF-Scale.

7 Those tornado characteristics that were
8 directly related to wind speed, such as the
9 probability of exceeding given wind speed at a point,
10 should a point be struck by a tornado, were factored
11 by switching to the EF-Scale and therefore
12 significantly impacted Revised NUREG/CR-4461 analysis.

13 The revised design basis tornado wind
14 speeds predicted by Revision 2 to NUREG/CR-4461 became
15 the basis for the final Revision 1 to Reg Guide 1.76.

16 Design basis tornado wind speed estimates
17 based on the EF-Scale are considerably lower than
18 those based on the F-Scale. For example the highest
19 design basis tornado winds speeds using the EF-Scales
20 predicted in Revision 1 to NUREG/CR-4461 was 300 miles
21 an hour.

22 Whereas the highest design basis tornado
23 wind speed using the EF-Scale, as predicted in
24 Revision 2 to NUREG/CR-4461 is 230 miles an hour.

25 CHAIR SHACK: Your slide should be

1 Revision 2, right?

2 MR. HARVEY: It's Revision 1 to Reg Guide
3 1.76. Revision 2 to NUREG/CR-4461.

4 CHAIR SHACK: Oh.

5 MR. HARVEY: Which is a point of confusion
6 all the time. The tornado missile speeds were also
7 recalculated for each tornado region based on each
8 region's new design basis tornado wind speed.

9 Note that a smaller and lighter automobile
10 missile is used for Region 3 as compared to Regions 1
11 and 2 because the heavier automobile used in
12 calculation for Regions 1 and 2 would have a lower
13 kinetic energy than in Region 3.

14 The result of an automobile missile
15 maximum horizontal speeds are approximately 35 to 40
16 percent of the maximum tornado speeds for each region.

17 The maximum speed calculated for the
18 automobile missile is also used for the pipe missile,
19 because the pipe can be a surrogate for a rigid
20 component of a larger missile, such as building debris
21 that may become airborne in the tornado wind field.

22 The resulting sphere missile maximum
23 horizontal speeds are approximately eight percent of
24 the maximum tornado speeds for each region. The pipe
25 and sphere missiles are assumed to impact at all

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1 heights, whereas the automobile missiles are assumed
2 impact only up to 30 feet above the highest ground
3 elevation within 0.5 miles of plant structures.

4 The missile vertical velocities are
5 assumed to be two-thirds of the missile horizontal
6 velocities.

7 Since design basis tornado wind speeds
8 were decreased as a result of the implementation of
9 the EF-Scale it was no longer clear that the revised
10 tornado design basis wind speeds at an exceedance
11 frequency of 10^{-7} per year would bound hurricane wind
12 speeds in all areas of the United States at the same
13 exceedance frequency.

14 This prompted an investigation, NUREG/CR-
15 7005, into extreme wind gusts during hurricanes at an
16 exceedance frequency of 10^{-7} per year. The NRC also
17 commissioned a second report, NUREG/CR-7004, to
18 calculate velocities associated with several types of
19 missiles consumed for different hurricane wind speeds.

20 The two new reports form the basis for the
21 new Reg Guide 1.221. These two consultant reports,
22 along with resulting Reg Guide 1.221 will be discussed
23 in the presentations that follow.

24 Any questions on tornados at this point?

25 CHAIR SHACK: Good introduction.

1 MR. HARVEY: Thank you. I'm going to turn
2 it back, to Selim, let's do musical chairs again.

3 MR. SANCAKTAR: This is Selim Sancaktar
4 from Office of Nuclear Regulatory Research. I have a
5 few slides just to set the stage for the next two
6 presenters, who will have some substantive and useful
7 technical information.

8 NRO came to research the user need to
9 provide a supplementary Reg Guide to the existing Reg
10 Guide 1.76. The supplementary Reg Guide would
11 investigate the hurricane as opposed to tornados.
12 This information on this slide pretty much, I think,
13 is what he talked about. So with your permission I'll
14 just skip it unless you have questions.

15 I think this Slide Number 10 pretty much
16 speaks for itself. When you look at it it shows that
17 in time the estimated wind speeds came down for design
18 basis purposes. So they came down from a range of say
19 300 miles per hour to 230. So this immediately begs
20 the question whether the tornado is still the limiting
21 phenomenon for the purpose of design basis.

22 Not only for the wind speed but also for
23 the missile speed. Because sometimes even with
24 slightly lesser wind speeds you can still get more
25 missile speed in hurricanes as opposed to tornado. So

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1 it's a little bit tricky.

2 So NRO requested us to investigate it and

3 --

4 MEMBER BROWN: Is that solely because of
5 sustained speed as opposed to gusts that you would get
6 in tornados?

7 MR. SANCAKTAR: No, it's --

8 MEMBER BROWN: I asked that because I've
9 sat through two hurricanes in the last four years at
10 my Miami Beach place and it was sustained, I mean, it
11 just didn't --

12 MR. SIMIU: I think I have a simple
13 explanation. A tornado comes and goes, it produces an
14 impact on the missile. And then missile picks up some
15 speed, the tornado goes and leave the missile alone.

16 MEMBER BROWN: Normal acceleration in other
17 words?

18 MR. SIMIU: Yes. In a hurricane you have
19 a wide wind field and it keeps adding momentum to the
20 --

21 MEMBER BROWN: Yes, that's what I meant by
22 sustained.

23 MR. SIMIU: Yes.

24 MEMBER BROWN: If it were a sustained
25 effect, you're continuously accelerating as opposed to

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1 settling. Which takes it and throws it like a
2 baseball or something.

3 MR. SIMIU: Yes, you are exactly on the
4 mark.

5 MEMBER BROWN: Okay. I just wanted to
6 make sure I understood the metric. Thank you.

7 MEMBER STETKAR: So when I came into this
8 there was already a White Paper being prepared,
9 internal to RES, trying to assess who could do this
10 job. What is technically, is this job doable.

11 Technically what we felt technically
12 qualified people for the wind aspect of it, wind
13 speed, were really few. We located like two and
14 luckily both of them did. And we feel --

15 CHAIR SHACK: They got the deal with the
16 NRC contracting? What a deal.

17 MR. SANCAKTAR: And it's my personal
18 opinion that we were lucky enough to get people who
19 are at this cutting edge of this field for wind
20 estimations, which is, as you alluded before, is
21 rather subject full of uncertainties and this and
22 that. So it's not a solid easy to do thing.

23 And for missile part we got Emil from NIST
24 and he actually wrote a book on the subject of that so
25 I don't have to say anything else. And based on their

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1 work we developed two NUREG/CRs, one is on the
2 hurricane wind speeds and the other one is on the
3 missile speeds.

4 The second one is really independent of
5 the first one. It gives results that what we can use
6 the speeds of the first one to figure out. We created
7 a draft Reg Guide and submitted the draft Reg Guide
8 with the two NUREG/CRs for public comments.

9 We received some comments and we addressed
10 them. The new Reg Guide follows the same format and
11 same kind of set up as its complimentary Reg Guide
12 1.76.991.

13 And we have provided the draft Reg Guide,
14 the Reg Guide, the NUREG/CRs and the responses to all
15 the public comments to other cognizant NRC offices,
16 not only NRO but also NRR, to obtain their
17 concurrences and we have done that.

18 So in the next part of the presentation we
19 have the two main authors of the two NUREGs who will
20 present each one. And we will start with Peter
21 Vickery of ARA. And at any point between now and the
22 next 30 minutes or so, at your convenience, we can
23 take a break. We can take it now or maybe --

24 CHAIR SHACK: No, let's go along a little
25 bit.

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1 MR. SANCAKTAR: Yes, okay. You just chose
2 the time as you wish to 2:45.

3 CHAIR SHACK: I don't know that we'll make
4 it to 2:45, but we'll make it a little longer. Before
5 Peter starts, since we haven't seen him before, can
6 you just give us a little background.

7 MR. VICKERY: Okay. My name is Peter
8 Vickery, I work at Applied Research Associates and
9 I've been there for 20 odd years. I guess the main
10 qualifications our firm had was the model that we, the
11 hurricane simulation model we've developed over the
12 last, since the early 90s I guess that's fully
13 progressed.

14 It's formed the basis of the American
15 Society of Engineers Standard Number 7, which is the
16 design standard for wind loads in the United States.
17 The hurricane model is used for that standard. It's
18 also used in FEMA's Hazus Model, the same simulation,
19 at least part of that model has been used in FEMA
20 studies.

21 Looking at coastal flood risk in North
22 Carolina and the Chesapeake and we also have some
23 proprietary models, they're offshoots of that model.
24 So it's fairly well accepted, I think it's a very well
25 accepted modeled. And it's viewed as a state of the

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1 art simulation model at the moment for hurricane risk
2 anyhow.

3 MEMBER BROWN: So they include storm
4 surges, water surges, as well or just wind, inland
5 wind effects or visual audits wind effects?

6 MR. VICKERY: Well the model can be used
7 to drive a storm surge model. So that's a separate
8 model to do that. We have done so. Both
9 probabilistically and with determinate simulation.

10 MEMBER STETKAR: Peter, I'm not a civil
11 engineer. So ASCE, what sort of recurrence intervals
12 do they typically use for industrial structures or
13 hospitals or schools or something like that?

14 MR. VICKERY: All right, it just changed.
15 Prior to the current edition, the 2010 Edition, the
16 nominal design was a 50-year or 100-year with the
17 appropriate load trackers on it, 100-year for the
18 hospitals.

19 And to the wind load factor with 1.6. And
20 then they've taken new tacks now and the wind load
21 factor is being set equal to one. And they're
22 designing that the hospitals for the 1,700-year wind.

23 MEMBER STETKAR: 1,700-year?

24 MR. VICKERY: Yes.

25 MR. SIMIU: I would like to add something

1 since you're not a civil engineer. It is not possible
2 to rely strictly on the new recurrence interval on the
3 load. You have to associate when that load, the limit
4 state that that load will induce.

5 And indeed, the 1,700 or 700 year loads
6 inherent in the design basis wind does not collapse
7 the structure. It does something less than that.

8 MEMBER BLEY: Okay, thanks.

9 MR. VICKERY: It's an elastic based design
10 so it's supposed to yield.

11 MEMBER STETKAR: I'm lucky I can build a
12 stick thing, so thanks. It helps.

13 MEMBER BROWN: To the uneducated like
14 myself in the civil engineering role, it sounds like
15 you went from a 1.7 design factor that you applied --

16 MR. VICKERY: 1.6.

17 MEMBER BROWN: Or 1.6, excuse me. To one
18 and then changed the time frame. That almost sounds
19 like you reduced the standard is --

20 MR. VICKERY: Actually if the hurricane
21 simulation model hadn't changed you would have got
22 exactly the same answers designing a building with the
23 old standard as with the new standard with the
24 appropriate load factor.

25 So in the interior of the country where

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1 the wind hasn't changed, you'll theoretically get
2 exactly the same answers.

3 MEMBER BROWN: So the longer period?

4 MR. VICKERY: The 50 years with a 1.6 is
5 identically equal, in the interior of the country,
6 with the 700 years with the 1.0 factor.

7 MEMBER BROWN: Okay from an analysis and
8 structural design perspective?

9 MR. VICKERY: Exactly the same.

10 MR. HARVEY: Same pressure.

11 MR. VICKERY: Same pressures. That was
12 the intent when we made this change, basically the 50
13 and 100-year to the 1,700-year. So that was the way
14 those values were set, be that right or wrong. And
15 then perhaps in the next edition something a little
16 more rationale will be applied to that.

17 MEMBER BROWN: Okay.

18 MR. VICKERY: Okay. So I'm going to give
19 some background on the simulation methodology that was
20 used to come up with the design, the 10^{-7} wind speeds
21 in that hurricane prone region of the states, and the
22 reason we use simulations for modeling hurricanes is
23 because there is not a sufficient historical record of
24 wind speeds that fit a distribution and move on.

25 So we have to use a simulation approach.

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1 Simulation approaches have been around, for
2 hurricanes, since the late 60s and have slowly
3 improved as the years have gone by.

4 Now in our model I'm going to talk about
5 what's called a Holland and B and Radius to maximum
6 wind model. Holland B describes kind of the general
7 shape of the storm.

8 So a B with a hurricane, like Andrew,
9 produces relatively strong winds. It had gust winds
10 speeds in the line of say 160/170 mile an hour
11 neighborhood. Hurricane Katrina, which had roughly
12 the same central pressure at landfall, only produced
13 peak winds, gust winds of 120 to 130 miles an hour.
14 And that is because the B describes the tightness of
15 the pressure grading.

16 On RMW models it's the size of the storm,
17 which is important for this, and the missile part.
18 And it goes through a lot of work on what we've done
19 to validate the pieces of the model. And then we've
20 made some changes to the ASC based model to address
21 the 10^{-7} study. And I talk a little bit about our
22 wind field model, which is, of course, important.

23 And then go into details that the model
24 changes and finally give the maps.

25 MEMBER BLEY: Somewhere in this discussion

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1 it would help me a lot if you'd reflect the details of
2 what you're telling us at a simpler level. So when
3 you build the simulation model, under some set of
4 hypothesis, you're modeling what the storms can do?

5 MR. VICKERY: Yes.

6 MEMBER BLEY: In a real crude expert
7 judgement elicitation model you're trying to integrate
8 everything at a high level and say how likely things
9 would be down here.

10 You're assigning somewhere a probability
11 distributions to the likelihoods of either the
12 parameters of the model or, if it's got multiple
13 models within it, which model controls and that sort
14 of thing.

15 So if you could give us a hit of where the
16 uncertainty is hiding here and where you're addressing
17 it it would help me a lot.

18 MR. VICKERY: Okay. I guess I'll go over
19 this slide in some detail then. Because this is kind
20 of an overview slide of how the simulation methodology
21 is done.

22 MEMBER BROWN: Just be careful. Don't get
23 too far away from the microphone.

24 (Simultaneous speaking)

25 MR. VICKERY: But basically the overall

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1 methodology is we start simulating storms out in the
2 open ocean. And what we've done is on initiation
3 points we view the historical record from the National
4 Hurricane Center directly.

5 And we sample, in this particular
6 instance, we sample, we did 10 million years of
7 storms. And it's all based on the 100-year record.
8 So what we have --

9 MEMBER STETKAR: From that 100 year
10 record, how many storms are you actually talking
11 about? About 200 or 300?

12 MR. VICKERY: That make landfall? Yes in
13 that neighborhood. Overall the number of storms
14 usually develop them all it's averaging about five or
15 six a year.

16 MEMBER BLEY: And also it would strike me
17 until the last 20 to 50 years it was probably pretty
18 vague about where the storm actually started.

19 MR. VICKERY: That's why we didn't want to
20 change it. We used the exact started points because
21 there are biases built in there. And we didn't want
22 to start messing around with trying to bias-correct it
23 and push the storms back.

24 The study points had to be consistent with
25 the way we model the tracks. And we were not willing

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1 to mess around with trying to bias-correct the --

2 MEMBER BLEY: And that's a historical
3 record of where people assume they started?

4 MR. VICKERY: Yes. Because as you go back
5 further and further in time the starting points shift
6 to the west. Well that's not really true. It's just
7 that the observations, they didn't pick them up until
8 they were further west. So we didn't want to back
9 that off.

10 Because if we started shifting those back
11 to the east a little further there's probably other
12 storms that initiated in the east that didn't even get
13 into the shipping lanes. We didn't want to mess with
14 it.

15 MEMBER BLEY: Let me just suggest
16 something and tell me how you'd deal with it. The
17 historical record of where the starting points were,
18 since they didn't pick them up as early. The storms
19 when they were picked up were much more well formed,
20 had higher winds, than probably where we pick them up
21 today.

22 Do you account for that variability in the
23 starting form of the hurricane in using these
24 historical starting points?

25 MR. VICKERY: Starting conditions are

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1 based on historical record. And that's correlated
2 with latitude.

3 MEMBER BLEY: And it would tell you what
4 was known about the storm at that point? Okay.

5 MR. VICKERY: Because of lot of it wasn't
6 that much known though.

7 MEMBER BLEY: That's what I figured. I
8 mean, ships report them and it was kind of random if
9 they would --

10 MR. VICKERY: And the pressure data going
11 back, it's kind of sketchy. I mean there's really
12 complete records from probably the 70s of pressure
13 data. And I'm going to go back to --

14 MEMBER BLEY: And out of all those storms
15 then, from the 70s up to now, you're probably talking
16 --

17 MR. VICKERY: Hundred-ish.

18 MEMBER BLEY: Hundreds. Well that's okay.

19 MR. VICKERY: And as you get closer to the
20 United States the historical record gets better. So
21 the landfall, the information we have on landfalls,
22 goes back to 1900s pretty good. Not perfect but we
23 treat it as perfect.

24 MEMBER BLEY: And we had some form of
25 measurements on those?

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1 MR. VICKERY: Yes and we concentrate on
2 the pressure measurements at landfall, not so much the
3 wind speeds. Because there's lot of subjectivity that
4 goes into these winds. And if people don't account
5 for anemometer heights terrain and what have you. Now
6 the pressures aren't affected so much by that.

7 MEMBER BLEY: Okay. Thanks. That helps
8 me.

9 CHAIR SHACK: One of the papers I tracked
10 back to from your references is James and Mason where
11 they take a slightly different approach. They argue
12 that you might introduce bias by using only the
13 historical data. So they sample around to get
14 different initiation points.

15 And I just, I assume you've looked at that
16 --

17 MR. VICKERY: We're initiating that for an
18 Australian model.

19 CHAIR SHACK: Yes, now they did it partly
20 because they didn't have as big a database as you did.

21 MR. VICKERY: Right.

22 CHAIR SHACK: But aren't you kind of
23 limited? I mean you also pick your starting
24 intensities from the historical database which would
25 sort of restrict you in some sense that you've only

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1 got a 100 year sample of that.

2 You know, but they try to, at least had a
3 distribution that gives them a chance of getting these
4 intensities that are greater than the observed.

5 MR. VICKERY: Well, what I should have
6 brought, a long time ago we did an example. We picked
7 a storm, I think it was Andrew actually. And we let
8 it go and the mean, well it kind of ballpark-ished
9 what Andrew did historically, but the spread is
10 enormous. So they forget where they've been after
11 about three or four time --

12 MEMBER BLEY: That would have been really
13 interesting to me.

14 CHAIR SHACK: You said they forget, you
15 mean the model forgets? So your mean works out fairly
16 decently, but the general extent, the boundaries are
17 expanded?

18 (Simultaneous speaking)

19 MEMBER BLEY: I would think of it
20 differently, Charlie, and then correct me if I'm way
21 off base here. The storm actually, I mean, that's
22 given the information about the storm. It could go
23 many different places. On average --

24 MR. VICKERY: Yes.

25 MEMBER BLEY: -- models doing, so the

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1 storm itself might go in many different ways.

2 MEMBER BROWN: Yes, I've got that point I
3 think.

4 MR. VICKERY: Yes we did some detail
5 studies on another version of the model for the
6 American Petroleum Institute actually, verifying the
7 model in a forecast, which it wasn't designed to do.
8 It's not tarot. And so coming back to that, the
9 modeling approach and where we initiate the storms.

10 In this 10^{-7} study really what we're doing
11 10,000 one hundred year simulations. So it's a number
12 of different realizations of that 100-year record.
13 What could have happened given our limited knowledge
14 of the distributions associated with the pressures and
15 the track and all that stuff.

16 So it's just different realizations that
17 could have produced some very, very strong storms
18 given what we know now about the history. So it's not
19 really a ten million year hurricane. It's what we
20 know now it's the one that has a chance of about one
21 in ten million of occurring. So don't think it was --

22 MEMBER BLEY: That's what I was hoping you
23 guys would have said early on. I was getting really
24 disturbed, that sounds rational.

25 MR. VICKERY: Well, it's a long story. It

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1 confuses a lot of people.

2 MEMBER BLEY: Yes obviously. Yes, we
3 don't need, it's not about --

4 MR. VICKERY: So the way the model works
5 is we initiate these storms and the model, these are
6 two examples from the simulation methodology where you
7 can see the pressures here. And what we've done is in
8 each five degree grid square we have statistics of
9 given where the hurricane is now and a couple of steps
10 back, depending on the grid square.

11 It predicts what the change in the
12 translation speed will be and the change in the
13 heading and what the intensity of the storm will be.
14 And the intensity is modeled with a relative intensity
15 concept. Not pressure concept. It gets converted
16 back to a pressure later in on the simulation process.

17 So over the entire Atlantic Basin we have
18 these grid squares, a set of statistics describing
19 what that storm is going to do next, given which grid
20 square it is and where it has been. And it slowly
21 tracks across --

22 CHAIR SHACK: And that's all interpolated
23 from historical data?

24 MR. VICKERY: Fit to historical data.

25 CHAIR SHACK: So fist principle stuff is

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1 not, is there first principle stuff --

2 MR. VICKERY: First principle part of this
3 is in the intensity model. Because that is based on
4 the maximum potential intensity of a hurricane, which
5 is based on the sea surface temperature.

6 MEMBER BROWN: Okay, so that's where you
7 factor that stuff in?

8 MR. VICKERY: Yes. Okay. So we track the
9 storm along and what you're seeing here, you probably
10 can't read the numbers, it's the central pressure and
11 this particular storm starts out at 997 millibars.
12 And it slowly intensifies, makes a curve and goes to
13 Tampa.

14 And once the simulated storms, as we move
15 them across the ocean, once they get within 500
16 kilometers of a site that we're interested in, we turn
17 on the wind field model and start computing the wind
18 speeds.

19 And we don't turn the wind field model on
20 until the last minute, so to speak, because it just
21 takes a lot of computational time. And then we track
22 the wind speeds.

23 And in this particular study we just score
24 the maximum wind speed that occurred at a site.
25 Maximum peak gust wind speed that occurred at a site.

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1 And so we have at the end of the day, a huge synthetic
2 record of peak gust wind speed at a number of sites,
3 produced from a suite of storms that, to the best of
4 our knowledge, match the statistics of today.

5 And this is just a flow chart of what I
6 just said. So I'm going to get straight to the
7 results of the simulation model in terms of the
8 validation portion. And what I've got plotted here
9 is, we've got all the various coastal regions, so I'm
10 going to pick this. Then I'll do Texas.

11 So this is all storms that make landfall
12 on the Texas coast. On the horizontal axis is the
13 return period in years. It goes from one to 1,000.
14 And you see how the historical record cuts out around
15 100 years. These are the land-falling central
16 pressures.

17 The dots, those open squares, are the
18 historic data, rank ordered and then using a simple
19 occurrence rate, Poisson Occurrence Model, inverted
20 into return period values. Texas, Louisiana,
21 Mississippi and Alabama and so on.

22 Now the light grey lines come from, again,
23 this re-sampling of, in this case it was 100,000 year
24 simulation, the re-sampling of that simulation to come
25 up with upper bounds and lower bounds of what the

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1 model had produced in that set of time.

2 In that period. And the historic data fit
3 into that air range, which we termed that I think it's
4 the 90 percent confidence range.

5 So based on our set of simulations the
6 model matches within a 90 percent confidence the
7 observations have taken place for all land-falling
8 storms along Mississippi and Alabama and so on.

9 And then we've got it all wrapped up
10 together for the Gulf Coast. And then finally, at the
11 bottom, the U.S. Coast. So we've, the best we can,
12 verified the model is getting the regional variation
13 in the central pressures at landfall. And the total
14 along the entire U.S. coastline.

15 And then we've broken up a little bit
16 finally --

17 MEMBER BROWN: Can you help me on one
18 thing? Are the lower pressures --

19 MR. VICKERY: Are bad.

20 MEMBER BROWN: Are bad. Okay, that's what
21 I thought I remembered.

22 MR. SIMIU: It's like a cup that you stir.

23 MEMBER BROWN: I understand, that's what
24 I thought I was remembering. I just wanted to make
25 sure I was in the right ballpark looking at the change

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1 in the curves.

2 MR. PASCAL: And then we broke it up into
3 some smaller coastal segments instead of entire
4 states. So Texas we broke up into four different bits
5 and we looked at that too.

6 I mean you can look at it in detail, but
7 we've looked at it in finer regions and in broader
8 regions and it passes the statistical test for
9 equivalence in the central pressure.

10 And you can see how the model moves on
11 beyond the period of record and starts to, this is
12 somewhere around Florida Regions 14 and 15, it starts
13 to flatten out as you get further on in time. I mean,
14 in probability.

15 So that describes the overall entire
16 model. Of the track, that's only the track portion of
17 the model. So it's the tracking, intensity and
18 occurrence rate. Because we go back here, these are
19 implied measures of occurrence in that return period.
20 So it's both the probability distribution and the rate
21 of occurrence are buried in this plot here.

22 MEMBER BLEY: Intuitively it sounds right
23 that it would tend to flatten out. But is there some
24 theoretical minimum pressure you can develop in a
25 storm?

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1 MR. VICKERY: Yes, we pulled that from
2 Kerry Emanuel's work on the maximum potential
3 intensity. And we reset the limit in the model from
4 what we were for ASC to a lower value. I can't
5 remember what the value is, but it's pretty low. And
6 the model actually never hit that value when we ran
7 the simulations.

8 MEMBER BLEY: Okay.

9 MR. VICKERY: Which is good. Then next
10 thing is this Holland B parameter. And I just go to
11 --

12 CHAIR SHACK: But suppose that we're
13 global warming fans. Could we heat up the ocean and
14 then see what happens then? Would that, you know,
15 that's one way to simulate what the effect of global
16 warming would be if it occurred?

17 MR. VICKERY: That's one way, it wouldn't
18 be right.

19 CHAIR SHACK: It wouldn't be right.

20 MEMBER BROWN: Sorry to burst your bubble.

21 CHAIR SHACK: I'm just trying to
22 anticipate questions that could come up at a full
23 committee meeting.

24 MR. VICKERY: Right, well when the ocean
25 heats up other there are studies looking at wind shear

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1 effect as well. And as the ocean is getting warmer
2 apparently the wind shear is increasing at well. So
3 wind shear inhibits the formation of hurricanes and
4 warmer sea surface temperatures allow for more intense
5 hurricanes.

6 MEMBER BLEY: So you get you fewer bigger
7 hurricanes is that what it is?

8 MR. VICKERY: The overall viewing right
9 now, and there's a lot of uncertainty on it, is that
10 in the future in a warmer climate. Maybe that's the
11 future, maybe it's not. There will be fewer category
12 1, 2 and 3s. But more Category 4s and 5s. Now we
13 have recently looked at the land-falling rate of
14 Categories 4s and 5s.

15 Looking at taking the AMO, the Atlantic
16 Multidecadal Oscillation, and separated it out into
17 warm years and cool years. And we're in a warm cycle
18 right now. That appears to be a result of a natural
19 variation, perhaps a long-term trend.

20 But it shows that on average the number of
21 Category 4s and 5s in the warm cycles is double what
22 it is, depending on where you are, up to double along
23 the Atlantic Coast than what it is on the long-term.
24 But the P Value associated with that is like 0.6/0.7.

25 MEMBER BROWN: What's that mean?

1 MR. VICKERY: It means the chances are --

2 MEMBER BROWN: It won't hit?

3 MR. VICKERY: Chances are the difference
4 is just statistical chatter and not a real difference.

5 MEMBER BROWN: Oh, okay.

6 MR. VICKERY: And we've found that time
7 and time again. You know, we're getting these ratios
8 that appear in the literature. But statistically you
9 can't say with any confidence that the data is showing
10 that. This is just for landfalls. It's not for --

11 CHAIR SHACK: This is landfalls associated
12 with the cycles, the warm cycles and the cool cycles.
13 Whether it really makes a difference, you're saying,
14 is statistically uncertain.

15 MR. VICKERY: Landfalls, right. We did
16 not look at storms in the ocean because we weren't
17 really interested in that. We were looking at
18 landfalls only. This is for another reason.

19 But that's what our conclusions are now.
20 And something we're going to put into one of our
21 models with a lot of warnings on it. So that's what
22 we've found.

23 Okay, so that gives you the track and the
24 intensity. So this next thing is the Holland A
25 parameter. Now I want to go down to this portion of

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1 the slide here.

2 And what I've got going across the axis
3 from the bottom, from left to right, is the distance
4 from the center of the storm divided by the radius to
5 maximum winds.

6 So that's just where the maximum winds
7 are. And on the vertical axis is the gradient wind
8 speed. This is all for the same central pressure and
9 the same radius to maximum wind and the same
10 translation speed of the storm.

11 And we changed the speed parameter from
12 0.75, which is down here, that produces a maximum wind
13 speed of 40 meters per second. And then we increase
14 the B to 1.5, that's kind of a biggish B, and it goes
15 up to about 55 meters per second.

16 So this B has a bigger factor on what the
17 magnitudes of what the wind speeds are. It's not a
18 perfect representation of the pressure/wind
19 relationship, but it's better than ignoring it which
20 is commonly done, I guess until our paper in 2000.

21 And we have a simple model for that, for
22 B, that basically says B will get smaller as storms
23 become larger and B will get smaller as storms move to
24 the north. There's some other parameters in there.
25 We put this into this nice little non-dimensional

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1 parameter.

2 But the bottom line is the further south
3 you are, the bigger the B. The further north you are
4 the smaller the B. And the bigger the storm on
5 average, the smaller the B.

6 The big storms have, all things being
7 equal, lower wind speed than the same storm that's
8 smaller. Because the smaller storm is going to be
9 associated with a bigger B. On average.

10 CHAIR SHACK: The Figure 2-7 in the NUREG
11 seems to have a different database for the B parameter
12 than you're showing here.

13 MR. VICKERY: Figure 2-7?

14 CHAIR SHACK: Yes, it's Figure 2-7. It's
15 referring back to the 2009 paper.

16 MR. SIMIU: On Page 14.

17 MR. VICKERY: Which NUREG?

18 CHAIR SHACK: The winds data.

19 MR. VICKERY: Oh, okay. Yes. That's
20 taken from a 2009 paper. And it's got more
21 information on it. What it showed was what the
22 current model is, which is this model here. And then
23 you see another line in the NUREG that's over here.

24 CHAIR SHACK: Yes, that's what bothered me
25 about the --

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1 MR. VICKERY: Okay. That's the old model.
2 So we were showing in that particular paper why the
3 wind speeds in the new model are lower than the --

4 CHAIR SHACK: Oh, so that's just the
5 model. I thought it was data that was showing the
6 distinct trend that you guys keep missing.

7 MR. VICKERY: No. Okay, maybe the text
8 needs to be adjusted to reflect that.

9 CHAIR SHACK: Well you need to put this
10 figure in.

11 MR. VICKERY: That's fine we can do that.
12 I mean I'm glad somebody's taking notes.

13 CHAIR SHACK: I mean this figure looks
14 like what I'd expect to see in a regression fit.

15 MEMBER STETKAR: Well the other one would
16 be perfect.

17 CHAIR SHACK: Yes, I could say that looks
18 like some of my data.

19 MR. VICKERY: Yes, the point was that the
20 new model and the old model are different and the
21 newer model produces lower wind speeds than the older
22 model. So the 2000 is the older model and the new
23 model is 2008. This work is based on the 2008 model.

24 And the next slide talks about the radius
25 to maximum wind. Without getting into a lot of

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1 details here, all it's really saying is as the central
2 pressure deficit increases, or the central pressure
3 decreases, storms on average get smaller.

4 So what's happening here is, on average,
5 as the intensity goes up the storms are going to get
6 smaller -- I'm sorry as the central pressure goes down
7 the storms are going to get smaller. And because the
8 storms get smaller the B on average is going to be
9 higher. So all your winds basically come from small
10 storms with Bs.

11 And they're going to affect relatively
12 small areas. If you look from a wind point of view
13 that's bad, from a storm surge point of view that's
14 good. The little storms don't produce much storm
15 surge. So the 10^{-7} wind --

16 MEMBER BROWN: Not even locally?

17 MR. VICKERY: No, not even locally. 10^{-7}
18 wind is not going to be associated with a 10^{-7} storm
19 surge. Okay, so this is just a summary of the event
20 model. The Hazus model was validated with landfall
21 data for 2007, we haven't updated since but two storms
22 since then are not going to make any difference.

23 It was calibrated to match the historical
24 period from 1900 to 2007 and we have statistical
25 models for the size of the B and the size of the storm

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1 that are based on less of a record. They're based on
2 30 years actually, or less.

3 MEMBER STETKAR: We're going to have to
4 take a break soon, or at least I will. But let me
5 just ask you about --

6 CHAIR SHACK: This slide is a good place
7 to break I think.

8 MEMBER STETKAR: It probably is, that's
9 why I wanted to get this one question in though. If
10 you drop back to your, it doesn't make any difference.
11 you said that you validated the model, the landfall
12 model, with some data.

13 And indeed I went back through NOAA
14 records, I've got 110 years worth of NOAA records on
15 landfall data as a function of intensity.

16 And for the entire U.S. Atlantic and Gulf
17 Coast your total landfall frequency seems to be pretty
18 comparable to the total data. However, when I start
19 to focus on individual areas, and I happened to take
20 the Texas coast because it was just the first chunk
21 that I ran into.

22 The frequencies that you're predicting
23 compared to the historical frequency of landfall
24 starts to diverge. And I found that, I found it in
25 Texas where I was seeing, not much higher but --

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1 MR. VICKERY: In our stuff?

2 MEMBER STETKAR: No, your frequency was
3 low compared to the historical landfall frequency.

4 MR. VICKERY: I don't believe that.

5 MEMBER STETKAR: Okay, I've got the data.
6 And I noticed it also up in New England and Long
7 Island. Now I didn't try to fight my way through
8 Florida and the Carolina's because it's, you know,
9 it's not my job to do that.

10 (Simultaneous speaking)

11 CHAIR SHACK: You've got to be careful
12 with the definition of what the hurricane is. Our is
13 a hurricane tromping the coasts in Texas.

14 MEMBER STETKAR: That's what I've done.

15 MR. VICKERY: Okay.

16 MEMBER STETKAR: You know, as best as the
17 NOAA record, they show peripheral wind effects, but
18 they, at least in my understanding of the data I have,
19 are crossing the Atlantic.

20 MR. VICKERY: Well this is the NOAA data
21 from HURDAT. It's from the official, if you want to
22 look it up --

23 CHAIR SHACK: Well in reading your 2000
24 paper it seems to indicate roughly the same thing.
25 You're under predicting the number of storms in Texas,

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1 in particular.

2 MR. VICKERY: Yes, but we're not now.

3 CHAIR SHACK: When I went through the
4 table and I did the Texas one I get, what did I get,
5 0.25 per year and it's point 0.36 on the 100-year
6 record.

7 MR. VICKERY: I'd like to see that record
8 you've got.

9 CHAIR SHACK: It's from Newman.

10 MR. VICKERY: That's old.

11 CHAIR SHACK: Well it's up to 1998, yes.

12 MR. VICKERY: No, I'd like to see that,
13 because I don't believe it.

14 MEMBER STETKAR: My record happens to come
15 from, if you want to write down the web, and it's 1900
16 through 2009, it's www.nhc.noaa.gov/ms-excel, E-X-C-E-
17 L, select hurricane strikes.20100204.xls. It took a
18 little bit of doing to find that.

19 MR. VICKERY: What we use --

20 MEMBER STETKAR: It's in the record now.

21 MR. VICKERY: We use something called TPC
22 Number 5.

23 MEMBER STETKAR: I don't know what that
24 is.

25 MR. VICKERY: It is the official landfall

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1 document. That has the land-falling characteristics
2 of all storms that make landfall in the United States,
3 with the exact latitude and longitude, name of the
4 storm if it's named. Central pressure if it's known,
5 no and the central pressure is known for all of them.
6 And the wind speed if it's known.

7 And also our plots here only include
8 storms that have central pressures less than 990. So
9 if there's some very weak storms they wouldn't show up
10 in the plots.

11 MEMBER STETKAR: In your plots.

12 MR. VICKERY: In our plots, yes.

13 MEMBER STETKAR: Yes, I mean this NOAA
14 database covers everything, you know, the Saffir-
15 Simpson Scale.

16 MR. VICKERY: But when you said, what are
17 you comparing it to with the model?

18 MEMBER STETKAR: Just landfall frequency.
19 Now if you've got a restriction on central pressure
20 less than X then you're predicted interval frequency
21 is going to be lower obviously than this.

22 MR. VICKERY: No. Yes, but where exactly
23 did you pull the model results?

24 MEMBER STETKAR: The model results?

25 MR. VICKERY: Yes.

1 MEMBER STETKAR: From the table, the Table
2 2.1 Hurricane Landfall Frequency by Saffir-Simpson.
3 That Saffir-Simpson Scale.

4 MR. VICKERY: Where? I want to make sure
5 we're on the same page here.

6 MEMBER STETKAR: It's on Page 28. It's
7 not in your presentation material here.

8 MR. VICKERY: No, it's in the report.

9 CHAIR SHACK: It's in the NUREG.

10 MR. VICKERY: Page 28, oh the model
11 results. I see.

12 CHAIR SHACK: That's what we used for the,
13 at least I --

14 MEMBER STETKAR: I use this also.

15 MR. VICKERY: Which one did you use? The
16 pressure?

17 MEMBER STETKAR: No, the second, well wind
18 speed.

19 CHAIR SHACK: It seems to agree better
20 with historic record if I do wind speed. I'm assuming
21 --

22 MR. VICKERY: Oh yes it should. Okay.
23 Our pressures agree with the --

24 CHAIR SHACK: With the NOAA data?

25 MR. VICKERY: Yes, but you've got to

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1 exclude Category 1s, to make this fair you really
2 ought to exclude Category 1s. Now the reason is our
3 model mathematically predicts the one-minute wind
4 speed. It's a mathematical representation, one-minute
5 wind speed.

6 Now, and this is a big discussion we had
7 with the National Hurricane Center, not just us, but
8 engineers in general. Their definition of a hurricane
9 is the maximum one-minute wind speed at the time of
10 landfall that could occur.

11 MEMBER BLEY: What's that mean?

12 CHAIR SHACK: That could have occurred?

13 MR. VICKERY: It's never measured. You
14 never have a measurement to prove that their wind
15 speed is right or wrong. And they can't, and they say
16 well, it could have occurred. Can't argue with that.
17 But the analysis that most engineers do don't support
18 their wind speeds.

19 And there are a lot of Category 1s out
20 there that aren't 1s, they're probably tropical
21 storms. And so in that respect there would be some
22 differences. And that's why we use pressures.

23 MEMBER BLEY: And that may be part of it.

24 MR. VICKERY: Because there's no argument
25 about what the pressure was. And at the lower

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1 threshold to be a hurricane, to be a Cat 1, you have
2 to have that 74 mile an hour.

3 Well, the model will probably
4 underestimate the Category 1s. Because it will
5 produce, you know, lower wind speed. So we won't
6 count it. We will not count it.

7 CHAIR SHACK: That was what was funny when
8 I looked at that table with the pressure is that, you
9 know, you seem to be, there's less Category 1s than
10 there are Category 3s for example, in Texas. Because
11 there's five times as many Category 3. And then
12 somehow that didn't seem right. But maybe that's
13 true.

14 MR. VICKERY: It's because we're
15 underestimate.

16 MEMBER STETKAR: They're going to
17 underestimate the one's too. Texas looks kind of
18 funny though when you get in the two to three range.

19 MR. VICKERY: We're going to underestimate
20 what NAC says is the number of one's. And still even
21 with their re-analysis, we disagree with some of their
22 re-analysis what the wind speeds are. But again,
23 that's why we concentrate on these distributions or
24 what the pressures look like at landfall.

25 Because those are the things you can't

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1 argue with.

2 MEMBER STETKAR: But you only have
3 reliable pressure measurement for the last 30/40 years
4 is that --

5 MR. VICKERY: Landfall is better.

6 MEMBER STETKAR: Landfall is better?

7 MR. VICKERY: And this would have been a
8 nice little study too that's come up recently. If you
9 went back and you look at the changes in the
10 historical record as Chris Landsey does these re-
11 analyses, how the wind speeds are changing. I'm
12 fairly confident that they pressures are not changing
13 nearly as much as the wind speeds are changing.

14 They seem to be more reliable, more
15 stable. For a better word. We've always stuck with
16 the pressures because of that. And that's how all
17 engineers who have been doing these simulations worked
18 with the pressures, they don't work with the wind
19 speeds. Because they're all estimated. The final
20 values are estimates.

21 MEMBER BROWN: Are those pressures at the
22 center of the storm, at the eye?

23 MR. VICKERY: Yes, they're the minimum.

24 MEMBER BROWN: But how many measurements,
25 normally, do you get in order to do that. I mean it

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1 just wasn't some of, what is it, the guys that fly
2 through, you get a gradient of pressures as you fly
3 through. And you'll average them?

4 MR. VICKERY: No you apply the profile.

5 MEMBER BROWN: Okay so you use a profile.
6 Okay, and I would think that the profiles from earlier
7 years are not as good as the profiles over the last 40
8 years.

9 MR. VICKERY: Correct.

10 MEMBER BROWN: Okay.

11 MR. VICKERY: Unless there happened to be
12 a measurement right at that time of landfall.

13 MEMBER BROWN: Yes, well I was just trying
14 to get a handle on your comment about using pressures.
15 And you go back 60, 70, 80 years and you say, yes
16 you've got some pressures. But I would suspect that
17 the profiles aren't as good at landfall in the
18 pressures as they are --

19 MR. VICKERY: They're not. But it's a
20 more stabilized --

21 MEMBER BROWN: I wasn't arguing with that.
22 I'm just trying to get a characterization.

23 CHAIR SHACK: Do you want more bad data or
24 fewer good data?

25 MR. VICKERY: I wouldn't argue that there

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1 could be, in fact be low biased. Yes, in the
2 historic. But some of the old ones, the 1935 storm,
3 somehow they got that one about right and they got it
4 at very, very low pressure at 892 millirems. Still
5 yet to be beaten in the U.S., Atlanta.

6 CHAIR SHACK: Well let me suggest we take
7 a break here until five of.

8 MR. VICKERY: And I'm going to start to
9 get into my real time.

10 CHAIR SHACK: Okay, we've got 15 minutes.
11 (Whereupon, the meeting in the above-
12 mentioned matter went off the record at
13 2:35 p.m. and went back on the record at
14 2:55 p.m.)

15 CHAIR SHACK: Okay, gentlemen, let's get
16 back to it.

17 MR. VICKERY: Okay. So the next thing I
18 wanted to talk about is the wind field model. That
19 given we've got the B and RMW in our track now, that
20 has to be converted into a wind speed. And it's done
21 by handing all that information off to the wind field
22 model.

23 Now I don't want to get into the details
24 of this ugly equation, but a very simple wind field
25 model for a hurricane can be described by this, the

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1 BDT term and this pressure grade interim along here.
2 So all that's saying as you get this type pressure
3 gradient the wind speed is faster and faster and
4 faster.

5 And that's basically, that type of
6 equation is used quite commonly in model hurricanes,
7 it's simple. Now our model is a two-dimensional
8 numerical model and the main reason we're using that
9 is because we add the effects of this frictional term
10 here.

11 And this frictional term changes the
12 characteristics of the overall wind field. And that's
13 the main term, so that's the main difference between
14 this simple numerical model and the very simple
15 gradient-balance model. A gradient-balance model,
16 which is this term and this term.

17 And I think I deleted the slide to what
18 that pertains to. I've got some stuff about talking
19 about the drag coefficient over the ocean here. I
20 think for the sake of time I'm going to skip those
21 because it's not that germane to wind speeds on land.

22 Okay not coming back to this gradient, I
23 don't have it explained here. This gradient-balance
24 model is the derivative and the Coriolis, which I
25 forgot about, matching the pressure-gradient.

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1 Now, as I said, that's a commonly used
2 model for estimating what the winds at the top of band
3 well, actually maybe 1,000 meters above the earth, are
4 like in a hurricane.

5 Now with this numerical model is divided
6 the wind speed results from the numerical model at
7 roughly this gradient height by the simple gradient-
8 balance model and drawn these contours here.

9 And so values greater than one indicate,
10 this is a storm moving towards the top here, and this
11 is basic radius, normal edge radius heading out
12 horizontally and directly from the center of the storm
13 here.

14 And this 1.2 in the top-left quadrant,
15 this means that the numerical model, or the slab
16 model, is predicting higher winds 20 percent higher
17 than you would get using the simple-gradient balance
18 models. And these results are similar to what you'd
19 get in full 3-D models, not exactly the same but it's
20 better than just using the gradient-balance model.

21 The Boundary Layer model we use, it's
22 derived from aircraft data where they drops on to the
23 ocean and they track the variation of wind speed with
24 height. We fit a modified log model to that.

25 Where we've got wind speed at height Z is

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1 equal to Z_0 over k to the friction velocity time the
2 logarithm of the height divided by the surface
3 roughness, Z_0 , just tells you how rough the ocean or
4 the land is.

5 Small numbers mean a smooth surface. And
6 we've modified it by this a to the z over h to the n
7 power, which causes this boundary layer model to suck
8 back as we get further up away from the ground.
9 That's basically the modification we've used.

10 And this simple model matches the
11 observations over the ocean very well. There are no
12 observations on land so we have to use this particular
13 model and then we use standard Boundary Layer Theory
14 to transition the hurricane boundary layer from the
15 sea to the land.

16 That's all well and good but at the end of
17 the day to find out how good your model is you've got
18 to compare to real wind speed data. So it's great to
19 have a fancy model, but it doesn't help you much if it
20 doesn't work, if it doesn't reproduce observations.

21 So at ARA we've produced estimates of wind
22 speeds for most significant U.S. land-fallen
23 hurricanes since 2004 for the Federal Government. In
24 terms of FEMA, and we've validated our wind field
25 models to comparisons to observations and our wind

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1 field models was also even used by NIST in their
2 Katrina/Rita wind speed publication.

3 The way we do these validations is, for an
4 example here, this is a wind --

5 MEMBER STETKAR: Peter, you said since
6 2004, that's like a dozen hurricanes?

7 MR. VICKERY: That's what we've been doing
8 for FEMA. We've validated going back to 1979.

9 MEMBER STETKAR: Okay.

10 MR. VICKERY: And done some other further
11 back more recently. But we've been funded by FEMA to
12 do this and they've published the results since 2004.

13 MEMBER STETKAR: Okay. Thanks.

14 MR. VICKERY: And one of the key things of
15 doing these validations of the wind speeds is you have
16 to know the terrain. All of the validations we do is
17 in something called standard open terrain conditions.
18 And basically an unobstructed wind slowdown down a
19 grass way is unobstructed terrain. And that's what
20 the model produces. It produces estimates of wind
21 speed in flat, open terrain conditions.

22 And this is an example here of the
23 anemometer at Miami International Airport. And you
24 can see for wind speeds coming from the east, north is
25 to the top of the page, it's pretty much flat open

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1 terrain. But for other directions it's not flat open
2 terrain.

3 And we have to correct these measurements
4 for these terrain effects. It's not a perfect
5 correction but it's better than not doing it at all.
6 I'll talk about that in a little bit.

7 This is another example for Hurricane
8 Katrina, where we have the anemometer is placed at the
9 center of this bulls eye here. And so if the wind's
10 coming from the south it's going to be good open
11 terrain. And the wind's coming from other directions
12 it's going to be affected by the upstream terrain.

13 And long story short, by estimating the
14 turbulence intensity you can back out comparisons,
15 back out adjustment factors. So in this example, for
16 winds coming from 30 degrees through 70 degrees, so
17 that's winds coming this direction through to about
18 here, we've had to increase the wind speeds by an
19 average of about 15 to 20 percent.

20 So what that's saying is the measurements
21 are underestimating the true winds by 15 to 20
22 percent.

23 MEMBER BROWN: Your reference was at the
24 top when you made your 30 degrees?

25 MR. VICKERY: Yes, so 30 degrees, well,

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1 it's from here, that direction through to that
2 direction.

3 MEMBER BROWN: Okay, I just missed your
4 first pointer movements. Thank you.

5 MR. VICKERY: Okay. And this is an
6 example here of model comparisons. And I'll skip
7 straight to this slide here, no I'll do this one.
8 There's a peak gust wind speed on this axis and time
9 plied on the horizontal axis. The solid line is the
10 model. The dots are from the observations, not
11 corrected for terrain.

12 I'm going straight down to the bottom
13 slide here, these are the dots adjusted for terrain.

14 MEMBER BLEY: And what's that wiggle out
15 at the right here?

16 MR. VICKERY: This wiggle?

17 MEMBER BLEY: Yes.

18 MR. VICKERY: Going to the eye.

19 MEMBER BLEY: Oh, okay.

20 MR. VICKERY: And as luck would have it,
21 or not have it, the anemometer recording system
22 failed. I think they ran out of fuel actually. But
23 it shows the importance of doing these adjustments for
24 the wind speed measurements.

25 A part of the peak gust wind speed should

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1 just, in a perfect simulation, the observed should
2 touch it about once every hour or so. Because it's
3 supposed to be a measure of the envelope of the peaks.

4 It should not go through the middle. A
5 perfect simulation the mean wind speed would go
6 through the middle here, which it doesn't, so it means
7 our corrections aren't perfect. And there's just some
8 more examples here showing some typical corrections.

9 This is showing an anemometer in Texas for
10 Hurricane Rita. You can see for winds coming out of
11 the north there's going to be corrections and the
12 correction factors in the neighborhood of 1.15.

13 MEMBER BLEY: And when you developed these
14 correction factors, are they based on local
15 measurements, local experts?

16 MR. VICKERY: Based on the turbulence
17 intensity, which is the gustiness in the measured
18 winds. You can back out what the effective surface
19 roughness had to be to produce that.

20 MEMBER BLEY: Oh, to produce that.

21 MR. VICKERY: And then you do the
22 corrections.

23 MEMBER BLEY: So they actually are based
24 on wind measurement?

25 MR. VICKERY: Yes based on measurements.

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1 MEMBER BLEY: And then for instance those?

2 MR. VICKERY: And here's just an example
3 of the Rita comparisons. Peak gust wind speeds before
4 correction and after correction. And again the
5 model's not perfect.

6 And this area in the model and it's
7 inability to be perfect every time it comes into our
8 uncertainty estimates down the road, which actually
9 drive some of the 10^{-7} winds.

10 So it's a validation step, it's very, very
11 important in addressing the inability of the model to
12 estimate these wind speeds perfectly. And this is
13 just a summary for Hurricane Ivan. These are all at
14 locations with data points. And then we've got
15 comparisons here, an X, Y scatter plot.

16 MEMBER BROWN: Is the variation, this is
17 an education question again. You talked about the
18 imperfectness of the model. Is it because the
19 computational end of it? You have to make certain
20 assumptions to fit within the computational ability of
21 the computers you've got? Or is it because of some
22 other unknown physical factors?

23 MR. VICKERY: A combination.

24 MEMBER BROWN: Some things that are
25 unknown, you just don't know the other factors that

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1 you supposed to --

2 MR. VICKERY: I'm going to touch on a few
3 of those in a few more slides. About where some of
4 these errors are coming from, or we think they're
5 coming from. But overall, I mean, there's not that
6 much bias. It's able to map out this regional winds
7 reasonably well.

8 Now just another example from Hurricane
9 Ike. I'll just skip over these. This is a plot
10 showing, if you look at one of the journal articles we
11 reference you can dig it out of there, but it's storm
12 by storm comparisons of model and observations.
13 Starting with Hurricane Wilma in the top left in 2005.
14 Going down to Hurricane Frederick in 1979.

15 And then we munched them all together
16 here. And these are all of the comparisons we have
17 done at the time this slide was prepared, which was
18 back in 2007 time frame I think. And there's a couple
19 of things you should pay attention to here.

20 We've got comparisons on land, are the
21 open squares, and we've lumped them all together. Now
22 you see the maximum wind speed we have is 60 meters a
23 second, so about 130 mile an hour peak gusts. That's
24 the maximum we have.

25 And there have been bigger wind speeds

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1 recorded in hurricanes, but that was not the maximum
2 in the storm. So this is only comparisons of the
3 maximum model wind speed compared to the maximum
4 observed wind speed. So for example --

5 MEMBER STETKAR: Run that by us, or by me
6 again. I didn't quite appreciate that subtlety.

7 MR. VICKERY: I wish I had my Hurricane
8 Charlie one. Let's pretend that these four
9 measurements weren't here. Okay so I would never know
10 what the maximum observed wind speed was in that
11 storm. So it wouldn't be included in that scatter
12 plot.

13 MEMBER STETKAR: Right.

14 MR. VICKERY: So that's all I'm saying.
15 So I would have had, let's say I had this point as my
16 very last point here.

17 MEMBER STETKAR: But I thought you said
18 something else, that there had been higher wind speeds
19 measured in storms.

20 MR. VICKERY: But not at the peak. So
21 let's say this one had died at 140 miles an hour and
22 kept on going. So we've got that 140 mile an hour
23 measurement, which is bigger than what was on the
24 scatter plot, but it didn't measure the peak.

25 The actual wind speeds were higher, so I

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1 can't include it in a model validation comparison.
2 Comparing the maximum values the model produced,
3 right.

4 MEMBER BLEY: Because he's trying to
5 compare the maximum.

6 MR. VICKERY: Trying to compare the
7 maximum --

8 MEMBER BLEY: He doesn't have that
9 measurement but --

10 MR. VICKERY: We don't have the
11 measurement.

12 MEMBER STETKAR: Yes, okay.

13 MR. VICKERY: And the biggest one recorded
14 was for Andrew before, about 15 minutes before it
15 failed. Maybe it was the biggest one, probably it
16 wasn't.

17 But these errors come about from a
18 combination of us not being about to model anomalous
19 features in the wind like down verse barrier in the
20 wind field, but our model with standard value A
21 theory, they come about from the inability of a single
22 B and a single RMW to model what can be quite a
23 complex structure of a pressure field.

24 It comes about from, in some cases, you
25 can actually have storms with a maximum wind speed to

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1 occur on the left hand side of the storm, because of
2 some other meteorological phenomena going on in the
3 storm.

4 You can have cases where you can have, a
5 pressure gradient can vary, you can have high pressure
6 on one side of the storm and a lower pressure on the
7 opposite side of the storm. That's going to produce
8 an asymmetry that we can't model.

9 So there's a number of these different
10 features that come in to the inability to do
11 appropriate wind model representation. And we've
12 tried to take care of, tried to treat that best we
13 can, by putting in a random modeling, a random error
14 term.

15 Based on the data we have, we use a
16 coefficient variation of ten percent, we get a sample
17 from that when we do our simulation. Talk to --

18 MEMBER BLEY: You use that same one
19 wherever you do this analysis?

20 MR. VICKERY: Yes, we have to have
21 something in there to take into account the fact that
22 the model is not perfect. And taking measurement and
23 validations, these validation studies are the tool we
24 used for assessing what that uncertainty is in the
25 wind field anomalies.

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1 CHAIR SHACK: Yes, now when you say errors
2 here, these are really errors in the wind field model.

3 MR. VICKERY: Well, that's, see some of
4 them is probably errors in the measurement too which,
5 but they get lumped into the --

6 CHAIR SHACK: Into the, right.

7 MR. VICKERY: -- into the wind model
8 summaries.

9 CHAIR SHACK: I mean, it doesn't involve
10 the tracking and --

11 MR. VICKERY: No.

12 CHAIR SHACK: -- any of that.

13 MR. VICKERY: That's treated as perfect.
14 But this is an example here, so all the pieces are put
15 together now, we have the wind field model and we run
16 it through the simulation.

17 So this is an example here, what we've
18 done for the United States, is we've gone back and
19 we've either estimated, using the same wind field
20 model, unfortunately, the mass of wind speed produced
21 by the hurricane anywhere in the United States.

22 Or we've used, we've also got different
23 folks' estimates of what the measured wind speeds were
24 in these hurricanes. So the dot, the plus signs here
25 are estimates based on the historical track in the

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1 wind field model, and the various colored symbols are
2 other peoples' estimates.

3 And the solid line here is the model
4 estimate. So what it's saying, and I apologize for
5 mixing units in between meters per second and miles an
6 hour, I collected these from various papers.

7 But what this is saying here is this is a
8 hurricane simulation model, it's producing a maximum,
9 100-year return period peak gust wind speed anywhere
10 in the United States, a mean estimate, is just a tad
11 under 80 meters per second, so about 170 miles an
12 hour.

13 So this gives you a kind of an overall
14 sense of how the model is comparing, at least country
15 wide or coast, yes, along the coast --

16 CHAIR SHACK: How do you assign a return
17 period to these experimental points?

18 MR. VICKERY: These odd points here?

19 CHAIR SHACK: Yes well, or any of them?

20 MR. VICKERY: The historical method is
21 easy, you just rack them and stack them. You've got
22 the probability, and you know the occurrence rate,
23 boom you're done.

24 CHAIR SHACK: Okay, so I just, through a
25 rank order.

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1 MR. VICKERY: Yes, and you've got the
2 occurrence rate so you can trim that to return period
3 very easily. The next thing we do is a little
4 trickier, is if you used order statistics for these
5 other measurements from, say Powell or Goldman or what
6 have you, you get a different order. So we've matched
7 their estimates with the order statistics we got from
8 the simulations.

9 So the order might in fact be wrong. And
10 then we've done this state by state. So there was a
11 question coming up about Texas. So our 100-year wind
12 speed anywhere in the state of Texas, we've got
13 examples here, the solid line is no wind field
14 modeling uncertainty, and the dashed line is with wind
15 field modeling uncertainty.

16 So our 100-year wind speed in the state of
17 Texas is about 70 meters per second, that's about 150
18 miles an hour. But at a single point in Texas, it's
19 a hell of a lot less. It's probably around 110, 120,
20 depending on where you are.

21 MEMBER STETKAR: It's 120.

22 MR. VICKERY: Does that help answer your
23 question?

24 CHAIR SHACK: No. But continue, it's
25 getting there.

1 MEMBER BLEY: And these curves now, are
2 the, these are the maximum, so you don't show
3 distribution on that.

4 MR. VICKERY: Right. These are the
5 maximum wind speeds --

6 MEMBER BLEY: Not of all years, right.

7 MR. VICKERY: -- historical record and the
8 simulation, with and without the wind-field modeling
9 uncertainty. And this is just to give people a sense
10 that the model is not out to lunch.

11 And when you put all the pieces together,
12 you know, the RMW model, the B model and the track
13 model and all that, it's producing reasonable answers.

14 MEMBER BLEY: So, over the years, you've
15 had this basic model for quite a few years now, right?
16 Which gets updated, but have there been key
17 occurrences, storms that have led you to see
18 discrepancies that led you to change the model?

19 MR. VICKERY: No.

20 MEMBER BLEY: Okay, so they're just
21 marginal improvements along the way and, are they
22 shifts or they have to do with the uncertainty.

23 MR. VICKERY: We had a shift from, we made
24 a shift in 2006 when we updated the hurricane, this
25 physical model for this Holland B parameter. Remember

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1 earlier --

2 MEMBER BLEY: Okay, that's fine.

3 MR. VICKERY: You saw that other plot,
4 that was a change in the Bs, and that made a big
5 difference. Other than that I think that's the only
6 real huge change we made. So and then the next bit of
7 sort of change we've made for the 10^{-7} study.

8 Okay, so our main model changes. The ASE
9 base model had a minimum radius to maximum winds of
10 eight kilometers, we've reduced that to now four
11 kilometers, so it's a pretty tiny storm we allow for.

12 Our initial set of, we use a reduced set
13 of wind speed tracks for our calculations, so we use
14 a basically a stratified sampling approach, where we
15 started out with 23.2 million hurricane tracks making
16 landfall in the U.S. and we've pared that down to 3.5
17 million, still a lot.

18 And now we've introduced a duration-
19 dependent gust factor which lowers the effects of the
20 gust factor for fast-moving small storms. That's only
21 because you don't have much time to generate a peak
22 gust wind speed, it is normally 1.5 times the mean.

23 MEMBER BLEY: Tell us a little more about
24 your second bullet.

25 MR. VICKERY: Yes, I'm going to.

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1 MEMBER BLEY: Okay.

2 CHAIR SHACK: That was one of my
3 calculations, I took the 23 million and divided by 10
4 million to get 2.3 --

5 MR. VICKERY: It's about 8 to 1.

6 CHAIR SHACK: -- and, but then when I went
7 back to the table, I don't get 2.3, I get 1.5.

8 MR. VICKERY: What table?

9 CHAIR SHACK: The landfalls, you know,
10 once it strikes, the landfalls in the U.S.

11 MR. VICKERY: Well this has nothing to do
12 with that.

13 CHAIR SHACK: I thought the 23 million was
14 the number of storms that made landfall, in the total
15 record, so I divided --

16 MR. VICKERY: Oh, sorry, that produced a
17 peak gust wind speed greater than some threshold.

18 CHAIR SHACK: Oh okay, so they're not
19 apples and oranges.

20 MEMBER STETKAR: But the 23 million should
21 be, I'm sorry.

22 MR. VICKERY: 23 million is 2.3 per year.

23 (Simultaneous speaking)

24 MR. VICKERY: -- there was a peak gust
25 wind speed greater than 50 miles an hour and it got

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1 counted.

2 CHAIR SHACK: So it's --

3 MEMBER STETKAR: It is larger, yes. I was
4 presuming you were going to say it had to produce a
5 peak gust wind speed greater than, you know, 130 miles
6 an hour.

7 MR. VICKERY: No, wind speeds are 50 mile
8 an hour thresholds for --

9 (Simultaneous speaking)

10 CHAIR SHACK: I thought we were only
11 counting hurricanes here, we are counting --

12 MR. VICKERY: At the end of the day, we
13 did.

14 CHAIR SHACK: Okay.

15 MR. VICKERY: The model produces all
16 ranges of tropical cyclones. The counting, the
17 validation stuff on landfall using NHC data, yes
18 hurricanes, but all the other stuff is there too.

19 So this is the distribution of the number
20 of storms that we had by maximum wind speed bin. So
21 for example, for a 200-mile-an-hour bin, we produced
22 about 10,000 storms and again --

23 MEMBER STETKAR: And this is from your 23
24 million --

25 MR. VICKERY: This is from the ten million

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1 year simulation or the 23 million mile storm.

2 MEMBER STETKAR: This is through 23
3 million population. I didn't count them up. So if I
4 look at this plot --

5 MR. VICKERY: This is anywhere in the
6 United States.

7 MEMBER STETKAR: I understand. If I look
8 at this plot and I counted up numbers of events down
9 in the tails, because when we're projecting very low
10 frequency extreme numbers, extreme storms, the
11 behavior of that tail in this sample, and I'll call it
12 a sample, is very, very important.

13 At the upper end of that tail you have,
14 kind of a couple of storms, about two or so, in bins
15 that are in the 300-mile-an-hour peak gust wind speed
16 range.

17 MR. VICKERY: Right.

18 MEMBER STETKAR: How would the behavior of
19 that tail, and if I back up sort of a quarter of the
20 way into that distribution change, instead of using
21 what you're calling a nominal 10^{-7} year simulation,
22 instead of having 23 million samples, I had 230
23 million samples for 2,300 million samples.

24 In other words how would the, if you ran,
25 instead of 23 million samples, you ran this out over

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1 what you're calling more years, how would the behavior
2 of that tail change?

3 MR. VICKERY: It would be a guess, but
4 remember we've also put this wind field modeling error
5 term --

6 MEMBER STETKAR: No, no everything is a
7 guess because it's a model, I mean --

8 MR. VICKERY: No, it would be a guess to
9 what the model change would make.

10 MEMBER STETKAR: Have you looked at it, I
11 thought you used to run this model for like a 10^{-6}
12 year sample, 100,000 smaller, or 100,000 --

13 MR. VICKERY: Yes, I used to run it for
14 100,000.

15 MEMBER STETKAR: How does the shape of
16 that tail change when you do that, when you compare
17 the --

18 MR. VICKERY: I've got some comparisons in
19 here of that, I think.

20 MEMBER STETKAR: On this type of plot,
21 comparison plot?

22 MR. VICKERY: No.

23 MEMBER STETKAR: Okay. But it would be
24 interesting to see how that would change as you go
25 from, if you got it for 100,000 versus ten million.

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1 MR. VICKERY: If I remember right we
2 didn't change the 100-year winds, or for the 1000-year
3 winds at all. In fact there's a plot coming up that
4 shows some of these comparisons I believe.

5 MEMBER STETKAR: Okay maybe I can
6 understand what it means.

7 MR. VICKERY: But we also sampled on top
8 of this, the random error term, it smooths this
9 distribution out in the tails too. It makes a big
10 difference. I don't have a plot of that, but the
11 random error term smooths out the distribution of the
12 tail.

13 MR. VICKERY: Coming back, we use this
14 weighting function where, though we had 1.2 million
15 storms of 60 miles an hour with gusts somewhere, it
16 doesn't make, I don't think, it doesn't really matter.
17 And then, so we only simulate one percent of those
18 low-end storms, and every time that one makes a
19 landfall it gets a weight of one over the number of
20 percent we simulated.

21 We retained every storm that produced a
22 peak gust wind speed on land greater than 170 miles an
23 hour, so there's no weighting applied to those storms
24 whatsoever. But now this is how we made our reduced
25 set. So we went from 23 million to three and half

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1 million.

2 And that's just, this is the total storm
3 weight, this is just the inverse of the previous plot,
4 and log space, so most of them are, a good chunk of
5 them are one.

6 And here are some examples here, goes out
7 to, I think what we did is we did a couple of sites
8 where we ran the wind field model for the entire time,
9 and it took for bloody ever, both the full set and the
10 weighted set, and it really didn't make any
11 difference.

12 So we are confident, based on this plot,
13 that the reduced set was enough, and coming back to
14 your tail question --

15 MEMBER STETKAR: Well, Peter --

16 MR. VICKERY: What you see is a tail
17 problem here.

18 MEMBER STETKAR: Yes, before you leave
19 this slide, though, these are the actual results from
20 the model that feeds the NUREG, is that correct?

21 MR. VICKERY: Yes.

22 MEMBER STETKAR: Okay. This --

23 MR. VICKERY: Or the random error term is
24 put on.

25 MEMBER STETKAR: Right, I understand.

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1 Yes, this is another set.

2 MR. VICKERY: Right.

3 MEMBER STETKAR: That has the error term
4 put on.

5 MR. VICKERY: Yes.

6 MEMBER STETKAR: Okay.

7 MR. VICKERY: And okay, the next step. So
8 these are the basic winds. The next step --

9 MEMBER STETKAR: Let's back up to that,
10 before we get into it. Because one of the fundamental
11 problems that I have, other than a shift in scale, is
12 if I'm looking at the Miami plot, the upper left hand
13 corner one that I can see a little bit better on my
14 piece of paper here.

15 Your logarithmic scale is, for people who
16 can't read it, is not a decade logarithmic scale, the
17 center point is a frequency of once in 10,000 years --

18 MR. VICKERY: Right.

19 MEMBER STETKAR: The right-hand vertical
20 line is a frequency of once in ten million years. So
21 that's a factor of 1,000 reduction in frequency. If
22 I look at it for Miami, that's an increase in peak
23 gust wind speed, if you'll allow me to round off, from
24 200 to about 235 miles an hour.

25 MR. VICKERY: Fifteen percent or so.

1 MEMBER STETKAR: Yes. What fundamental
2 physics is driving the fact that I can predict, with
3 some confidence, a factor of reduction in frequency of
4 1,000, once in 10,000 years to once in ten million
5 years, with an increase in peak gust wind speed of
6 only about 15 percent, 200 to 235 miles an hour?

7 If I plot that, and I did, if you could
8 plot it on a linear scale, you know, it would look
9 like a vertical line. If you plot it on a logarithmic
10 scale it's still a very, very steep drop-off. There
11 must be something in terms of fundamental physics that
12 drives that notion.

13 MR. VICKERY: That it only increases by 15
14 percent?

15 MEMBER STETKAR: Over an estimate of, you
16 call it recurrence period, I call it frequency, over
17 an estimated reduction in the frequency by a factor of
18 1,000, not a factor of ten.

19 MR. VICKERY: Because you have to have all
20 these exactly right conditions to get this potential
21 intensity to be one. It's not sampling those right
22 conditions until maybe once in a while.

23 MEMBER STETKAR: That's, the phrase that
24 you just said, it's not sampling those except for once
25 in a while --

1 MR. VICKERY: Based on our current period
2 of record, because it's using the tropopause
3 temperature data is a 50-year record. Sea surface
4 temperature is a 100-year record, but it just re-
5 samples current years, and it has to hit the right
6 combination of low tropopause temperature and high sea
7 surface temperature, and to produce the very, very
8 high, or very, very low central pressure demonstrated.

9 MEMBER STETKAR: The question I have then
10 is, how sensitive is the shape of that distribution
11 out in that tail, to your sampling algorithms and the
12 number of samples you're taking and, you know, you're
13 limited by your data set.

14 MR. VICKERY: Yes. It's a good question
15 that I don't know the answer to it.

16 MEMBER BLEY: Have you done any stratified
17 sampling, something like that?

18 (Simultaneous speaking)

19 MEMBER STETKAR: Well this is stratified
20 sampling.

21 MR. VICKERY: It already is a stratified
22 sampling.

23 MEMBER STETKAR: Have you looked at
24 conversions of your sampling results? You know if
25 it's a Monte Carlo sampling, I'm assuming --

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1 MR. VICKERY: Yes, we have in the past.
2 I didn't readdress it this time.

3 MEMBER STETKAR: I mean, that's really,
4 really important if you're trying to predict, if
5 you're results are very, very sensitive to a random
6 hit of one sample --

7 MR. VICKERY: Yes, I don't think they are,
8 but --

9 MEMBER STETKAR: You don't think they are?

10 MR. VICKERY: No, but, again we --

11 CHAIR SHACK: Well I worry more about the
12 fact that the initial conditions are limited. You
13 know, you can, as long as the initial conditions span
14 only a certain range, you can hit them as many times
15 as you want.

16 MEMBER STETKAR: That's the other part of
17 the problem and, you know, so I'd be more inclined to
18 assume that, that in fact sets my true limits. He
19 could sample until hell froze over --

20 CHAIR SHACK: Well, that's true. I mean
21 if you had perfect sampling, you're still limited by
22 the range of your --

23 MR. VICKERY: Again is --

24 CHAIR SHACK: But, you know is this range
25 of variables, you know, could they shift? Well they

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1 could presumably shift that we had some anatomy
2 changes, but --

3 MR. VICKERY: If you get any climatic
4 changes they could shift. Yes, it's undivided data,
5 that's really all I can say to there.

6 MEMBER BLEY: Is there a way, when you do
7 this kind of modeling, to unravel exactly what's
8 contributing to these events out on the table? What
9 congruence of conditions have led to these --

10 MR. VICKERY: Yes, what we found in the
11 path is actually the very low tropopause temperatures
12 that drive it. It's the low tropopause and the high
13 sea surface temperature at the same time.

14 At the end of the day, let me move on a
15 little bit further on here, these results are driven
16 by the, actually the wind field, probably, uncertainty
17 drives them, so we weren't particularly concerned
18 about it.

19 MR. SIMIU: Yes but for example, Peter,
20 you have no radius of maximum wind speeds less than
21 four kilometers. So you ran around a trillion
22 simulations and still you won't have, you have a
23 censoring based on judgement and experience, so it
24 limits the tail, I believe.

25 MR. VICKERY: I would probably go, well I

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1 might go the other way actually but, because you've
2 also reduced your strike area too. But, yes, we have
3 cut it off at four kilometers, which is pretty damn
4 small.

5 But not very much I can say to expand,
6 we've done some sanity checks at the end, comparing
7 it to Emanuel's stuff, to see if it's in the ballpark.

8 MEMBER STETKAR: It is just that I'm, you
9 know, I'm stepping back, you know, Lord knows I don't
10 know anything about this simulation stuff, or the
11 model. Everything I read gives me a lot of confidence
12 that you really, really understand the behavior of a
13 cyclonic wind field pretty well.

14 I step back to regulatory decisions that
15 are being based on the assertion that we have
16 confidence that a change of 15 percent in peak gust
17 wind speed results in a reduction of a factor of 1,000
18 in frequency, because people are making decisions on
19 the same level.

20 This is a 10^{-7} and I need to design to 220
21 miles per hour peak gust wind speed, if I follow it
22 along the Texas coastline. Well if that's off, you
23 know, it's an artificiality of the 10^{-7} .

24 A 200 and whatever I said was, 200 miles
25 per hour, is a factor 1,000 times more likely. And if

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1 the tail of that distribution is off a little bit on
2 this very, very sharp logarithmic scale, for a 10^{-7}
3 frequency, maybe I have to design to either a much
4 higher wind speed or, you know, I'm making a wrong
5 regulatory type decision. You follow what I'm
6 saying?

7 MR. VICKERY: Yes, because we did not do
8 a formal uncertainty study.

9 MEMBER STETKAR: Yes. You don't know the
10 shape of that if I were to fit an uncertainty
11 distribution on those curves. You don't know the
12 shape of those uncertainties, how they're --

13 MR. VICKERY: Well it's going to be, it
14 will be limited at the top by the maximum --

15 MEMBER STETKAR: That's what I was going
16 to ask you. What is, theoretically, you said there
17 are some notions of theoretical maximum, you know, I
18 don't even know the phraseology, the minimum pressure.
19 Is there a maximum, you know, associated with that, in
20 up or down on peak gust wind speed, I mean, as a
21 practical matter?

22 MR. VICKERY: That's a good question, I
23 don't know --

24 MEMBER STETKAR: Yes, you're projecting
25 those two hits out in the tail of the previous

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1 distribution were up in the sort of 300 mile an hour
2 a range, but only a couple of hits which, is there a
3 theoretical upper bound that says, well we just can't,
4 for something that's called a hurricane, we just can't
5 get something that's higher than 320, 330 miles an
6 hour?

7 MR. VICKERY: Not that I know of but, you
8 mean --

9 MEMBER STETKAR: That would give us a
10 sense of what that's --

11 MR. VICKERY: Yes, I understand --

12 (Simultaneous speaking)

13 MR. VICKERY: -- what's going on, I mean
14 the frictional, I guess the best way to do that is to
15 run a full numerical model. To look at the potential
16 upper limits, to try and get a handle on that.

17 Otherwise, it's hand waving. I need to
18 kind of quit hand-waving, say, that's the really, the
19 only way to get a handle on that. And still, you're
20 going to be limited by the ability of that model.

21 You're going to need a very, very fine
22 grid. So I have to kind of bail on that one. Because
23 I hit, I mean I can't answer it any better than that.

24 MEMBER STETKAR: Okay, thanks.

25 MR. VICKERY: It certainly adds to the

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1 uncertainty.

2 MEMBER STETKAR: Thanks.

3 MR. VICKERY: I'm going to try to speed up
4 now. Next thing is the, I'm going to go over this
5 very quickly. An enhanced gust factor, well I'm going
6 to skip the math but, the gust factor approach we use
7 is based on a, it's a theoretical estimate of what the
8 mean gust wind speed will be in a turbulent manner
9 blowing at the surface based on a one-hour stationary
10 record.

11 And in open terrain that gust factor is
12 about 1.52, it varies some with wind speed. Give them
13 an hour, and the turbulence associated with standard
14 open terrain, which is typically in the order of 10,
15 12, 15 percent, I don't remember the exact number.

16 But as your period, your hour reduces, you
17 don't have enough time to hit that maximum, so the
18 probability of getting 1.5 times the gust wind speed
19 goes down. And as that period gets shorter and
20 shorter, that effective gust factor goes down, down,
21 down.

22 But we have, we together the little model
23 that takes into account, it accumulates the gust
24 factor as the storm goes through. So a very, very
25 short storm, very tight, fast-moving storms so you

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1 don't have a lot of time, you'll have an effective
2 gust factor that's lower than 1.5.

3 And we looked at the effect of that in
4 here for South Florida with our full storm set, and
5 with this non-stationary gust factor, it reduced the
6 wind speeds by a little bit.

7 And the same deal in New York, but again,
8 you also, again in New York, remember we've got this
9 kink at the high end. So this is an example of not
10 running enough simulations.

11 Next one is we have a translation speed
12 adjustment, I won't get in too much details on this,
13 but the model, we believe when this is going to get
14 very, very fast-moving storms is not behaving
15 correctly, so we've reduced the effective translation
16 speed that's -- the storm took, translates it, in this
17 case 30 meters per second, but the translation speed
18 we feed into the wind field model is actually 20
19 meters per second.

20 And that's, we've done that because, when
21 you're looking at the 1938 hurricane, with very high
22 translation speed, the results just looked, weren't
23 quite right. And since we've made that change, it's
24 validated well for Hurricane Juan in Halifax which was
25 a fast-moving storm well North.

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1 This is a tough, you have these gust
2 factors kind of being all over the place, plotted
3 versus mean wind speed, this is from Hurricane Wilma.
4 It's very hard to see here, but the mean gust factor
5 is 1.5-ish, and this is just showing the observations
6 are bouncing all over the place.

7 MEMBER STETKAR: This is the 15-minute,
8 you used the term mean, is it a 15-minute mean?

9 MR. VICKERY: These days it's a 15-minute
10 mean.

11 MEMBER STETKAR: Yes that's, okay. I
12 think some of them were ten minutes, but that's okay.

13 MR. VICKERY: And here's another example
14 of wind field modeling uncertainties with this Holland
15 B parameter. You can see in this, whatever hurricane
16 it is, Hurricane Allen with a pretty decent central
17 pressure deficit of 106 millibars, so about 907, yes
18 about 907 millibars central pressure.

19 The thin line is the observations from
20 aircraft, and the solid line is the model, so it's not
21 matching perfectly. And the same deal with the wind
22 speeds, it's underestimating the peaks here, but
23 that's another contributor to the error term.

24 And again, this all lumps into this plot
25 we've developed before so, errors are coming around

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1 from not getting the gust factors right, or the
2 distribution of the gust factors, because of anomalous
3 winds, B, its B representation, not being able to do
4 a perfect representation of the hurricane.

5 So we've all fed it into a catch-all error
6 term for the wind model. And this is what that wind
7 modeling error term does, is without the wind field
8 modeling is for the South Florida here, it's tailing
9 off at ten to the minus seven, around 230 miles per
10 hour, and with this uncertainty bumps up to 260 miles
11 an hour.

12 And you'll see in New York it smooths out
13 the tail shape a little bit, because you're adding
14 extra randomness to the process.

15 MEMBER BLEY: You change the direction of
16 curvature too. Yes, it's really significant.

17 MEMBER STETKAR: Remember this is a log
18 plot.

19 MR. VICKERY: This is an example of an
20 anomalous wind speed, a few anomalous wind speeds
21 popping up and changing the shape of the curve.

22 And by adding this additional uncertainty
23 term, you screwed up the tail. It's something that
24 the insurance companies do all the time to estimate
25 their tail probabilities for high losses. Sampled

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1 again from some simulations that were done before.

2 Okay, so that's the model. These are all
3 the grid points we used.

4 MEMBER STETKAR: What, the 25 mile grid,
5 or is it fixed grid?

6 MR. VICKERY: It's a fixed grid, I don't
7 remember. It's tighter at the coast, very tight at
8 the coast.

9 MEMBER STETKAR: Yes.

10 MR. VICKERY: I don't remember what our
11 spacing is inland. Okay, this is, first off we wanted
12 to compare, this is the NRC model results for the 100-
13 year and then the 1,000-year wind speeds and think the
14 next one compares it to ASCE 7.

15 So at the 100-year, look at the 140 mile
16 an hour here in the NRC model, and at the ASCE model.
17 It shifts a little bit so the NRC model is a little
18 bit weaker than the ASCE 7, which is consistent with
19 the gust factor change. And, you know, that's it. If
20 the gust factor change that would do that, make that
21 change.

22 MR. HARVEY: Which version of the ASCE
23 model are you using?

24 MR. VICKERY: It's the 2009, it is the
25 most current version.

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1 MR. HARVEY: Okay.

2 MR. VICKERY: It's the 100 year wind
3 speed. And finally for the 10⁻⁷ view kind of results
4 here for Texas was the 220 mile an hour winds. Up at
5 the tip of the Mississippi Delta they're up around 260
6 miles an hour. Down in the Miami area, the 290 mile
7 and hour in the Keys.

8 North Carolina coast, this is where the
9 Brunswick nuclear plant is, it's around 220 miles an
10 hour. And then you're getting up to the northeast,
11 it's not surprisingly the lot, the biggest around 190
12 miles an hour, in the Nantucket area, and not much in
13 Maine.

14 And this is a map just showing where the
15 hurricane basis designed winds exceed a tornado, it's
16 not that big an area but mostly Florida and little
17 bits of North Carolina and Texas.

18 MEMBER STETKAR: And along the Gulf Coast.

19 MR. VICKERY: And along the Western Gulf
20 coast of course.

21 MEMBER BLEY: Very narrowly.

22 MR. VICKERY: Very narrow, yes.

23 MEMBER BLEY: Well, it's got to be right
24 along the coast line.

25 MR. VICKERY: So our overall summary, and

1 I'll be right on time. Okay, the original model was
2 developed and validated using data since 2007, and
3 when that model was developed we had the new
4 statistical models for the B and radius to maximum
5 wind.

6 It was extensively validated, the wind
7 field model portion was on shore and off shore. This
8 wind field model, the approach used here, was also
9 used in ASCE 7 but played a much smaller role because
10 you're only in the 100,000 year kind of range there.

11 The model's been very thoroughly peer
12 viewed, and it was used to develop the ASCE 7 designed
13 wind speeds.

14 Now this time around for the NRC, we've
15 updated the model, we started with the ACSE 7 wind
16 speed model, we reduced the radius to minimum radius
17 maximum wind to four kilometers.

18 We have a reduced storm set to enable all
19 the model run sets that we've done. We have a mean
20 gust factor now that takes into account storm
21 duration. I didn't review this before I came here.

22 Okay, the $10^{-6}/10^{-7}$ winds are strongly
23 impacted by the wind field model uncertainty term
24 which I already talked about. And then we did kind of
25 a back of the envelope validation study, not really

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1 validation but kind of a sanity study.

2 And we took that 290 mile an hour wind on
3 land and we assumed it hadn't been fully transitioned
4 into full over land wind speeds gusts. So the gust
5 factor was back in the range of 1.7/1.8, this 290 mile
6 an hour corresponds to roughly one minute sustained
7 wind speed over water in the range of 190 to 220 mile
8 an hour, there's a swath in there too.

9 And then we compared that to the, so
10 that's 85 to 98 meters per second. That's a humming
11 wind, nevertheless. And then the Massachusetts
12 Institute of Technology on their website, this is
13 Kerry Emanuel's group, they published their maximum
14 potential intensity match and we looked at August,
15 September and October.

16 And in the south Florida area the ten
17 percent exceeds probability mpi, is greater than 90
18 meters per second. So this suggests that our results
19 are in the right range and comparable to a those of
20 another study that uses, it's a different approach but
21 they also, they just estimate what the maximum
22 potential intensity is.

23 It's not out to lunch, assuming the
24 maximum potential intensity theory is any good, so
25 we've taken that as gospel. So that's kind of the

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1 summary of where the model came from what we did, and
2 the resulting results. The final results. Any more
3 questions?

4 CHAIR SHACK: No, I noticed you did that
5 frequency study to estimate one possible shift in the
6 temperatures. The other discussion is you could do
7 the temperature changes in the ocean just to look for
8 potential effects. But, I mean, these are all kind of
9 guesswork things.

10 MR. VICKERY: Yes, John has this doubtful
11 look in his eyes.

12 MEMBER STETKAR: Well, but, I mean, you
13 know, I appreciate the presentation I just don't
14 understand why, I'd like to more carefully understand
15 why the types of projections that I've done,
16 admittedly, you know, with hours worth of effort.

17 MR. VICKERY: Are so much higher?

18 MEMBER STETKAR: Are so much higher. I
19 believe it's because they're more, they're not quite
20 estimates, they're more area estimates.

21 MR. VICKERY: Yes, and I tried to do that,
22 you know, as I said, I took first the Texas coast and
23 looked at, that's obviously wrong. So then I narrowed
24 down to one county and that's also a bigger area but
25 it's starting to get into typical footprints of

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1 reasonably severe hurricanes.

2 You know, if I look at a 20/30 kilometer,
3 you know, radius of strong winds for example.

4 MEMBER STETKAR: Well what was the number
5 you had, the 100-year number that you had based on
6 what you had given.

7 MR. VICKERY: For a Texas or the single
8 county?

9 MEMBER STETKAR: Texas.

10 MR. VICKERY: Now I have to, hold on let
11 me pull up the Texas model.

12 MEMBER STETKAR: That's a comparison we
13 can do.

14 MEMBER STETKAR: The 100-year for Texas?

15 MR. VICKERY: Yes.

16 MEMBER STETKAR: Peak gust?

17 MR. VICKERY: Yes.

18 MEMBER STETKAR: Hold on let me get a
19 curve that I can look at. Well I've got a range, the
20 problem is I have a range.

21 MR. VICKERY: That's fine.

22 MEMBER STETKAR: And I don't get --

23 CHAIR SHACK: The differences are big
24 enough you don't need to worry about --

25 MEMBER STETKAR: The differences are big

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1 enough I don't need to worry about it because my about
2 50 or 60 year range is somewhere in the 170 to 230 or
3 240, I'm sorry about 170 to about 200 mile an hour
4 peak gust, three second peak gust wind speed. And
5 your 100-year of 10^{-2} is on the order of a 120.

6 MR. VICKERY: Right and for the state we
7 get any --

8 MEMBER STETKAR: That's state.

9 MR. VICKERY: Okay, well on the coast
10 we're getting 157/158, that's still lower than what
11 you're getting.

12 MEMBER STETKAR: I'm trying to understand,
13 you know, why what I'm doing is just insane.

14 MR. VICKERY: Yes, there's some kind of
15 error there, either in the way the wind speeds are
16 estimated.

17 MEMBER STETKAR: Well as I said, mine is,
18 what I did was I just took the simple NOAA data
19 estimating Saffir-Simpson category, which is
20 approximate and the ranges of wind speeds.

21 MR. VICKERY: Because your 200 miles an
22 hour is more than we get, and the data would suggest,
23 for the entire United States.

24 MEMBER STETKAR: Well, but that 200 miles
25 an hour is just a 30 percent increase on the upper

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1 bound of a CAT, what would be a CAT 4 hurricane.
2 That's all that is.

3 MR. VICKERY: Okay.

4 MEMBER STETKAR: It's not a statistical
5 sampled thing because I have no idea what the actual
6 distribution of wind speeds within, you know, that
7 family set is.

8 MR. VICKERY: Right.

9 MEMBER BLEY: So you took like a CAT 3 and
10 just distributed it over --

11 MEMBER STETKAR: I didn't distribute it,
12 all I have is the lines drawn, this is the upper bound
13 this is the lower bound, I have no idea what the
14 distribution looks like between --

15 MEMBER BLEY: When you calculate, I'll say
16 at a point. But you look at a point and you look at
17 everything your models generated through that point
18 and come up with an estimate. So we don't have
19 estimate of how broad that represents, it's just the
20 maximum of everything generated at a particular place?

21 MR. VICKERY: Well we could, everything at
22 that one particular point, now if we'd saved
23 everything, which we didn't do, we could have produced
24 an estimate of what the maximum wind speed was
25 anywhere, in any size region you want.

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1 MEMBER BLEY: You could pick that county.

2 MR. VICKERY: Because we have the event by
3 event maximum wind speeds. We had them, we don't have
4 them any more I don't believe.

5 MEMBER STETKAR: What is, and as I say
6 we're running short on time so we should stop this.

7 MR. VICKERY: We should move on.

8 MEMBER STETKAR: The curious thing for me
9 is that I only have a snapshot of historical data over
10 110 years that I've converted into some sort of simple
11 minded exceedance curves.

12 At the point at which my data end, the
13 slope of those exceedance curves looks like the slope
14 of your exceedance curve. In other words, except for
15 the fact they're shifted in wind speed substantially
16 and as that shift in wind speed as you translate out
17 through this logarithm and plot makes a huge
18 difference.

19 MR. VICKERY: Yes, it does.

20 MEMBER STETKAR: You know down to the 10^5
21 10^{-6} , 10^{-7} frequency range.

22 MR. VICKERY: Right.

23 MEMBER STETKAR: Because the shapes seem
24 to be about the same.

25 MR. VICKERY: Well the shape should be

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1 about the same.

2 MEMBER STETKAR: It seems that the
3 exceedance, you know, notion is working, you know, it
4 seems to be comparable. It's just, I don't understand
5 the dramatic shift which has, you know, a hugely
6 magnified effect way down at those low frequencies.

7 MR. VICKERY: Right, and we'd have to look
8 at it together in a lot more detail to sort out the
9 differences.

10 MEMBER STETKAR: Yes, and that's what Bill
11 --

12 CHAIR SHACK: I think it's time to move
13 on. Now we're going to take these winds and fling
14 things with them.

15 (Off microphone discussion)

16 MR. SIMIU: So I will go to the slide
17 which says the reports documents and approach to and
18 results of the calculation of hurricane borne missile
19 speeds for the design of nuclear power plants.

20 The missile spectrum, we use missile
21 spectrum based on discussions with the staff, the NRC
22 staff. Some of the missiles are the same as the
23 missiles that are used for tornado.

24 For the design basis tornado missiles but
25 in addition the staff requested that we look at two

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1 additional missiles. And it is the last item here,
2 states that it is a safety concern that wind-borne
3 siding missiles may compromise the structural
4 integrity of the nuclear island Seismic Category 1
5 structures.

6 This addition was required because of the
7 characteristics of those missiles differ significantly
8 from those of the four missiles tabulated in the
9 Regulatory Guide 176, Revision 1.

10 So the theory that underlies our
11 calculations is simple. It's Newton's second law.
12 And the force of that acts on the missile is
13 proportional to the square of the relative velocity of
14 the missile.

15 Of wind field with respect to the missile,
16 which is why we see some differences. There the
17 hurricane minus v_{mh} and v_{mv} . And A, the parameter, A
18 here, is proportional to an estimate of the average
19 draft coefficient. An estimate of the exposed area
20 and the mass, and the rule being the specific weight,
21 the specific mass of air.

22 So these are the two equations that govern
23 the horizontal and the vertical velocity of the
24 missile. The following assumptions were made and some
25 of them differ from the assumptions that are made in

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1 the case of tornados.

2 First, hurricane updraft speeds are
3 negligible, this is not the case for tornados.
4 Missiles starts motion with zero initial velocity from
5 an elevation H. I do not know what that elevation H
6 is, in RG 1.76 it was assumed that H, by convention,
7 that H was 40 meters.

8 So we took this initial condition, the
9 initial elevation, is of measure or is commensurate
10 with the time that the missile is exposed to the wind
11 flow. If the missile is near the ground the gravity
12 force brings it very quickly at the ground and then
13 there is no more aerodynamic force.

14 So we took all, we performed calculations
15 for all those initial heights. Wind speeds,
16 assumption Number 3, vary with heights above ground
17 in accordance with the power law. One power law for
18 open terrain, I think the exponent view was 1.1
19 divided by seven. And for suburban terrain where the
20 exponent of the power law was, if I recall well, one
21 divided by four.

22 And the fourth assumption, a simplified
23 assumption, the missile drag coefficient is
24 independent on average of missile position or relative
25 missile speed with respect to the wind flow.

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1 There have been some attempts, maybe 30
2 years ago, to follow the missile and it's rotate and
3 it's rotation stumbling throughout the trajectory,
4 many of the assumptions that accompanied this
5 procedure looked arbitrary and difficult to support.

6 So the results didn't differ much from
7 when the Assumption 4 is used. So following the
8 procedure that we used in Regulatory Guide 1.76, I
9 think it was, we used Assumption 4, it's the same
10 assumption that was used for missiles.

11 This shows the missiles spectrum schedule
12 45 a large automobile for Regions 1 and 2. A smaller
13 automobile were used for tornado Region 3, and a solid
14 one inch diameter solid steel sphere.

15 We started these additional missiles, for
16 which we assume that the drag coefficient was 1.2,
17 steel board batten siding coated with PVC, this was
18 not my choice.

19 (Off microphone discussion)

20 MR. SIMIU: A slab and a plank. That was
21 Jerry's suggestion, it was, if you will, scientific
22 curiosity, I believe that. But also the realization
23 that these things can happen. So he wanted us to know
24 what would be the consequence of it.

25 For all open and suburban terrain cases

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1 the equations of motion have to be solved numerically
2 but we wanted to check our numerical solver.

3 And we found that if we assumed that the
4 wind speed is uniform with height, doesn't vary with
5 height, it was possible, by a variety of tricks that
6 I learned in my sophomore year, to find a solution of
7 the differential equation, enclosed form.

8 And then we tested the numerical solver
9 for this and we were very relieved to find that the
10 results were the same. So we inferred from that that
11 the results for the open and suburban terrain cases
12 where the winds profile and the power law structure
13 would be correct also.

14 Okay this slide, which is difficult to
15 read, is reproduced from the report and provides wind
16 speeds corresponding to various missile speeds are not
17 corresponding to various wind speeds at ten meters
18 above ground in open terrain. These are the speeds
19 that you get from Peter's calculations. So this is
20 the standard wind speed and the corresponding missile
21 speeds tabulated for various types of missiles.

22 CHAIR SHACK: For the Boundary Layer
23 Variation you have in the velocity, is that similar to
24 the Boundary Layer Variation that Peter showed or that
25 you --

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1 MR. SIMIU: Yes, no actually Peter shows
2 a modified logarithmic law which deviates from the
3 logarithmic law considerably at very high elevations.
4 Our elevations never exceeds 40 meters because we
5 don't have updrafts.

6 So we just used, we didn't use a
7 logarithmic law, which we could have used the American
8 Society of Civil Engineers standards. ASCE 7 uses the
9 power law, because it's been around for 50 years and
10 codes change slowly.

11 In fact, because there's a discrepancy
12 between ASCE profile, and the profile that's
13 meteorological, researchers use, which are algorithmic
14 and the logarithmic that was introduced in the
15 standards through the back door somehow.

16 But this wouldn't make much difference.
17 So we calculated terminal horizontal wind speeds and
18 we calculated terminal total wind speed. That is the
19 result of the vertical and of the horizontal.

20 And then we created those graphs that
21 cover all possible missiles via this Parameter A. And
22 again we do it for various wind speeds and we get the
23 results here.

24 And I have here a few examples of wind
25 speeds. For 125 meters per second, three second

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1 hurricane wind speed, at ten meters above ground in
2 open terrain.

3 The calculated maximum horizontal wind
4 speeds over open terrain were $H=40$, are approximately
5 and then we list them here. We also list in color the
6 corresponding speeds when the three second hurricane
7 wind speed is 103 meters per second.

8 And then we list in parentheses the
9 corresponding values for initial heights, 20 and ten
10 meters per second. So here the speeds we calculated
11 which are higher than their counterparts, for tornados
12 for the reason that Mr. Brown pointed out earlier.

13 So this is a summary of the tornado wind
14 speeds which show that the wind speeds are indeed
15 smaller in tornados than in hurricanes. And because
16 I wanted to keep my presentation short, I am now at a
17 point where I can state the conclusions, for the seven
18 types of missiles of interest tables are provided and
19 the report is very thick.

20 Because I provided tables for all possible
21 conditions as well as requested, legitimately by the
22 Nuclear Regulatory Commission.

23 So of the seven types of missiles of
24 interest, tables are provided which list missile
25 speeds and the time the missile reaches the ground

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1 level for hurricane wind speeds at ten meters above
2 ground in open terrain, ranging from 40 meters per
3 second to 150 meters per second.

4 In increments of five meters per second
5 and for flow over open terrain and over suburban
6 terrain, both horizontal missile speeds and total
7 missile speeds. The resultant of horizontal and
8 vertical speeds, are listed.

9 Plots showing those missiles as function
10 of parameters characterizing the missile properties
11 are also provided. Similar tables and plots list
12 maximum as opposed to terminal missile wind speeds.

13 The terminal wind speeds is not
14 necessarily the highest wind speed because as the
15 speeds in the boundary layer decrease, they decelerate
16 the velocity of the missile and that's why we picked
17 the maximum velocity speed during its trajectory. And
18 this is my admittedly prosaic presentation, every
19 thing is exact except for the parameter A.

20 CHAIR SHACK: Yes. What's your source for
21 the parameter A for the drag coefficients? The sphere
22 I can --

23 MR. SIMIU: Yes, you have in front of you
24 a historical monument, I am historical monument, in
25 the sense that I was present at the creation, I did

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1 the calculations that went into the 1974 document. A
2 long time ago, I was a young man then.

3 And so we consulted the staff, we looked
4 at, there used to be a compendium of drag coefficients
5 by a German scientist that came to the United States
6 after World War II by the name of Hoerner, it was a
7 classic, and now you look it up, you look the CDs on
8 internet.

9 CHAIR SHACK: Okay, I'll do a Google
10 search for it.

11 MR. SIMIU: Yes so, see 1.2 is a
12 reasonable drag coefficient, except to use that
13 smaller drag coefficient for the sphere. I think that
14 was 0.4. I think I have it written even in that
15 presentation.

16 So, as I said, it's prosaic, it's
17 approximate, I didn't make any decision, and will not
18 make any decision. I was not mandated to make any
19 decision on what the missile will come down from.

20 A 40 meters, 30 meters, 20 meters, it
21 probably depends on the sites, on the surroundings, on
22 the judgement of the staff for any particular power
23 plant, so we only provided the basic information. And
24 the bulk of the work was done by my coworker, who is
25 a Professor of Math at the University of Maryland,

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1 name is Potra.

2 And I also, in addition to acknowledging
3 Florian, my coworker, I wanted to say that in my very
4 long career, I never worked with a sponsor that was as
5 meticulous and helpful in checking everything I did,
6 and finding errors, thank you.

7 (Laughter)

8 MR. SIMIU: Here and there.

9 MEMBER STETKAR: Really small errors.

10 MR. SIMIU: Tolerable.

11 MEMBER STETKAR: Tolerable errors.

12 MR. SIMIU: After being corrected they
13 were tolerable.

14 CHAIR SHACK: As you say, it's a very
15 useful piece of work.

16 MR. SIMIU: Thank you.

17 CHAIR SHACK: For people, to do these
18 things.

19 MR. SIMIU: I think it's clean. I mean,
20 it's clean and transparent. In fact, we also supplied
21 the software to NRC, we put it on our site when the
22 report would be released so that anyone who knows that
23 particular -- I don't remember what kind of software
24 it is, but they can do their own calculation.

25 CHAIR SHACK: Well I like the little

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1 tricks to do the closed form solutions. It goes back
2 a long way.

3 MR. SIMIU: It's when, a long way and I
4 have to brag, I did that. I didn't allow the
5 mathematician to do it, he just checked it. I was
6 rather proud of myself because I did that stuff in the
7 year of the Lord 1952.

8 CHAIR SHACK: Any additional questions?
9 If we were going to come forward to the full
10 Committee, how should we do that. Yes, right.

11 MEMBER STETKAR: That's an excellent --
12 I'm going to take this one, then. It's an excellent
13 question, though. We cannot bring it to the full
14 Committee.

15 CHAIR SHACK: Yes, you know that's a good
16 question. I mean, I think it's, you know, it's
17 basically a done deal, so the work is coming out.
18 This was more for our information, it was really not
19 a --

20 MEMBER STETKAR: I mean I haven't become,
21 I'm convinced that I'm wrong, but I'm not convinced
22 that they're right. And I don't know, but on the
23 other hand if I step way back from it --

24 CHAIR SHACK: Well you're certainly not
25 going to figure that out at a full Committee meeting

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1 --

2 MEMBER STETKAR: Absolutely not --

3 (Laughter)

4 MEMBER STETKAR: Where is it clear, you
5 know, before I die I'm going to figure it out. But
6 the, if I step way back from the whole purpose of
7 this, identifying areas in the United States where the
8 risks, I'm sorry, the limiting condition might be a
9 hurricane, is certainly a useful exercise.

10 You know, and this exercise has done that,
11 and qualitatively it certainly makes sense. I mean,
12 there's nothing counterintuitive about the locations
13 that have been identified along the coastlines in
14 Florida, where hurricanes ought to be more limiting
15 than tornados, that makes a lot of sense.

16 The design basis wind speeds that people
17 are using in those regions are like any other design
18 basis event, you have to design to something. So
19 people are going to design to whatever those design
20 basis wind speeds are. I have no problem with that
21 either.

22 As in any kind of design, you design to
23 the double-ended guillotine shear with a presumed
24 simultaneous loss of offsite power with a single
25 failure. That's a design basis, it's an arbitrary

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1 design basis.

2 The only question is then, putting
3 confidence in the fact that we believe that those
4 design basis conditions will occur once in ten million
5 years.

6 CHAIR SHACK: Well let's just say that
7 they're sufficiently conservative.

8 MEMBER STETKAR: They're reasonable for a
9 design basis, but presuming that the frequency of
10 those conditions would be once in ten million years,
11 may be questionable. Maybe once in 10,000 years or
12 once in --

13 MR. SIMIU: If you take --

14 MEMBER STETKAR: -- 100,000 years, but not
15 once in ten million years. That's a risk argument,
16 it's not --

17 MEMBER BLEY: What we'd normally want to
18 see is for a given wind speed, the uncertainty in that
19 wind speed, what we have here is a maximum wind speed,
20 and not a real clear statement of --

21 MEMBER STETKAR: How the uncertainty is in
22 each part of the process.

23 MEMBER BLEY: Is there a chance it could
24 be higher, that sort of --

25 MEMBER STETKAR: Well, yes, I mean it's

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1 characterized as the best estimate maximum, whatever
2 that means.

3 MR. SIMIU: My sponsor for the 1974
4 documents, when I expressed my own dismay on, upon
5 hearing this ten million years criterion, told me,
6 it's qualitative and it's there for legal purpose, it
7 doesn't have real physical significance. That's what
8 --

9 MEMBER STETKAR: Historically I believe
10 that's the case. However we've learned an awful lot
11 in the last 30, you mentioned '74 or whenever, in the
12 last 30 or 40 years about the dangers of over-
13 characterizing our confidence in very small numbers.

14 MR. SIMIU: Yes.

15 MEMBER STETKAR: And for a whole variety
16 of --

17 MR. SIMIU: 1.999999.

18 MEMBER STETKAR: Well, and especially for
19 natural phenomenon, I mean people have characterized
20 for example, you know, we design to the 1000-year
21 flood and then try to rationalize why we had two 1000-
22 year floods in the last decade, that type of activity.

23 That some of those recurrence intervals or
24 frequencies that were perhaps thrown about 30 to 40
25 years ago as being very rare events, we're learning,

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1 are still rare events, but not nearly as very rare as
2 whatever people presumed they would be in the past.

3 That's, as I said, that's my, my sense of
4 this exercise is, on a qualitative basis to define a
5 set of more limiting conditions along coastal areas
6 for the designers.

7 I think it makes a lot of sense. It's
8 just saying that we have confidence that those
9 conditions will occur once in ten million years, as
10 compared to the fact that maybe the true mean
11 frequency might be once in 10,000 years, which is a
12 huge difference. It's still a very rare event.

13 MR. SIMIU: The ten million is a figure of
14 speech, so to speak.

15 MEMBER STETKAR: Well, but the problem is,
16 it is used in a regulatory process and it's used by
17 other people in terms of a level of confidence about
18 design margins.

19 MR. SIMIU: Have you heard of an approach,
20 a reliability approach, called information-gap
21 approach?

22 MEMBER BLEY: No, Dennis tends to read
23 much more than I do --

24 MR. SIMIU: If you wish, there is a new
25 blog, I have nothing to do with it, but if you give me

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1 your cards, I'll send you, I just received it two days
2 ago. It's been around for a long time. It's been
3 used in, for military applications, probability of
4 missilling by the Iron Dome protective device.

5 So maybe that would be useful to look at.
6 I don't guarantee that it will be useful --

7 MEMBER BLEY: It would be worth looking
8 at, sure.

9 MEMBER STETKAR: It would be worth looking
10 at, certainly.

11 MR. SIMIU: If you would write your emails
12 on a piece of --

13 MEMBER STETKAR: I have a paper.

14 MEMBER BLEY: When we're done, we'll give
15 it to you.

16 MEMBER STETKAR: We'll get it to --

17 (Simultaneous speaking)

18 MEMBER BLEY: Yes, it's worth looking at.
19 I mean, there are lots of techniques. I'm kind of
20 like, though, I mean this, I might have a greater
21 feel, I have a pretty comfortable feeling that this is
22 conservative and it, you know, seeing some details
23 under the results might make me understand it better,
24 you know --

25 MR. VICKERY: What kind of details?

1 MEMBER BLEY: Well, the spread, how broad
2 the spread is underneath your maxima. You know what
3 the results of the simulation look like in terms of,
4 I'm not saying that right --

5 MR. SIMIU: I'd like to add one little
6 point. I don't know how valid it is, but it may be
7 worth considering. If you simulate, if you have 100
8 years worth of data, and you try to fit a probability
9 distribution to those data, I mean seems time for a
10 new distribution.

11 What we found, with absolute regularity,
12 is that those probability distributions have limited
13 tail lengths, they stop somewhere --

14 MEMBER BLEY: Have limited what?

15 MR. SIMIU: Tail lengths.

16 MEMBER BLEY: Yes.

17 MR. SIMIU: The tail is not infinite. It
18 stops somewhere. I tried reading Kerry Emanuel's
19 papers to find out where they stop, and I wasn't able
20 to. From his thermodynamic considerations, I couldn't
21 get to put my finger on a wind speed.

22 There can be no wind speed greater than
23 190 miles per hour.

24 MR. VICKERY: No, there is nothing there.

25 MR. SIMIU: It is not in there. But it's

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1 interesting that the extreme value theory, for what
2 it's worth, seems to tell you that the tail is not
3 infinite, and that what's --

4 MEMBER STETKAR: That helps an awful lot
5 when you're doing simple, you know, extrapolations, it
6 at least gives you some anchor point --

7 (Simultaneous speaking)

8 MEMBER STETKAR: -- zero were very, very
9 small.

10 MR. SIMIU: A fundamental question that
11 one may ask is, how valid is extreme value theory, it
12 is based on some assumption itself. But I thought it
13 was an interesting indication. It stops somewhere.
14 From my 100 years of data, I get maximum tail, and I
15 know that it's wrong.

16 It may be very different, but it still
17 tells me for all locations, 53 locations along the
18 Gulf Coast and Atlantic Coast, it tells me it never
19 goes infinite.

20 MR. VICKERY: Yes, but it is very
21 subjective as to exactly where that tail is, and it
22 can change the results significantly.

23 MEMBER STETKAR: That's true. The
24 subjectivity, I mean in terms of, engineers worry
25 about subjectivity in terms of precision. I come back

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1 to the difference between precision and accuracy.

2 MR. VICKERY: Yes, you can be precisely
3 wrong.

4 MEMBER STETKAR: You can be precisely
5 wrong, but you might be in the right ballpark.

6 MR. VICKERY: Right.

7 MEMBER STETKAR: And perhaps being in the
8 right ballpark with some subjective estimates is more
9 useful, is more valuable than just saying, well we
10 can't do it precisely.

11 MR. VICKERY: Yes, it's kind of what the
12 simulation approach is at the end of the day, right?

13 CHAIR SHACK: Well I suppose we could go
14 back and look at this maximum potential intensity
15 approach, which is a physical basis for a limit, if --

16 MR. VICKERY: Yes you could, but you also
17 need to consider the whole thing together. Look at
18 the, you know, you've got uncertainty in the missile
19 population, all of, what missiles you're going to
20 choose, their starting heights and all that stuff.

21 You can't just take the hazard and isolate
22 it, you have to look at the whole thing together.
23 Because you don't exactly know yet which one is
24 driving --

25 MEMBER BLEY: Yes.

1 MR. VICKERY: -- the uncertainty at the
2 end of the day.

3 MEMBER BLEY: That's certainly true
4 enough.

5 MR. VICKERY: The missile spectrum is
6 incredibly simplified. Now is that more important
7 than being off by ten miles an hour? Or not? I mean
8 that's, you need to look at the whole picture, on the
9 perforation equations, the whole bit.

10 You can't get focused on one part of the
11 problem, to find out where your dollars are best
12 spent.

13 CHAIR SHACK: My concern is that we have
14 some additional questions, but these additional
15 questions that are better pursued at a full Committee
16 meeting.

17 MEMBER BLEY: Certainly not.

18 CHAIR SHACK: I think, you know the better
19 question is --

20 MEMBER STETKAR: Well, John did sort of
21 like a, you know that 100,000, if you've got that
22 binning for the 100,000 so you can compare it to the
23 10^{-7} bins.

24 CHAIR SHACK: At current use of the
25 population --

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1 MEMBER STETKAR: The population --

2 CHAIR SHACK: -- of events.

3 MEMBER STETKAR: -- of wind speeds. Your
4 destination would be 23 million over your five mile
5 per hour bins.

6 MR. VICKERY: Yes.

7 MEMBER STETKAR: Peak gust winds for your
8 --

9 CHAIR SHACK: Is there an equivalent for
10 your 100,000 miles? Or your 100,000 simulation? Just
11 so we could see what the difference looked like?

12 MR. VICKERY: I've never plotted it out
13 for that one.

14 MEMBER STETKAR: That comparison, as I
15 said by itself doesn't answer, you know, my
16 wrongheadedness about plotting the data, but it does
17 answer a bit about potential sensitivity of tails of
18 the simulation sampling processes.

19 MR. VICKERY: We don't have 100,000 years
20 on the same grid.

21 MEMBER STETKAR: Okay.

22 MR. VICKERY: That's the tricky part.

23 MEMBER STETKAR: The previous grid was a
24 much larger grid?

25 MR. VICKERY: No, we have different grids

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1 floating around. We have, we just did a half a
2 million one on a zip code grid, but that doesn't help.

3 CHAIR SHACK: Well of course you did that
4 other one for, what was it, eight kilometer, you
5 changed the minimum --

6 MR. VICKERY: Yes, but that's --

7 CHAIR SHACK: The RMW which would affect
8 this, right?

9 MR. VICKERY: Only at the tails.

10 (Simultaneous speaking)

11 MEMBER STETKAR: God, I would hope it
12 would not affect the flat part of that distribution.

13 MR. VICKERY: Yes, I wish we could even,
14 well we had some disk crashes so we lost some of the
15 data from the 10^{-7} study. We have a lot of it, but
16 not all of it, if we had to quickly come up with that.

17 For the one stage we did have a full set
18 of a small -- oh we have the, we may still have the
19 full sets at some individual locations. We could
20 extrapolate, I mean, pare down to 100,000, take the
21 first 100,000.

22 MR. SIMIU: How long would it take you to
23 run the data?

24 MEMBER STETKAR: You'd have to think about
25 that.

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1 MR. VICKERY: Well the problem is you've
2 got to rerun all those damn tracks, that's what takes
3 all the time.

4 CHAIR SHACK: Yes, suppose you just take
5 the 10^{-7} data set and start plotting the first X,
6 second X, and see how it changes?

7 MR. VICKERY: I'll --

8 MEMBER STETKAR: That would, I mean that
9 would give you a feel for how that tail shapes --

10 CHAIR SHACK: Floats around.

11 MEMBER STETKAR: -- floats around.

12 MR. VICKERY: Right. I guess the only
13 thing I can do is look to see if we have that
14 available. I'll make a note to see if I can dig that
15 out.

16 MEMBER STETKAR: I guess the bigger
17 concern is, you know, is it worth bringing before the
18 full Committee?

19 MEMBER BLEY: I'm not sure that we need
20 the full Committee.

21 CHAIR SHACK: No, I mean if we had a
22 problem I'd bring it to the full Committee, but I'm
23 not sure that our problems rise to the level that they
24 need to be addressed at the full Committee.

25 MEMBER STETKAR: That's --

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1 (Simultaneous speaking)

2 MEMBER STETKAR: In terms of the
3 Subcommittee, you know I'm obviously with, having the
4 tails, then my problem is simply characterizing that
5 design basis, wind speed as a 10^{-7} per year wind
6 speed. I have absolutely no -- assigning a frequency
7 to it.

8 MR. SIMIU: You know would save the
9 situation, if instead of saying that it is the 10^{-7}
10 1000ths wind speed, you could say it's an estimate of
11 the 10^{-7} wind speeds.

12 MEMBER STETKAR: No, I feel much more
13 comfortable saying, well we've done a lot of
14 analytical work, there's a lot of uncertainties and
15 we're going to use, as a design basis wind speed, this
16 wind speed without assigning a frequency to it, to
17 avoid this notion that we're designing for a once-in
18 a-ten million-year event, or once-in-100,000-year
19 event, or once-in-10,000-year event.

20 CHAIR SHACK: Gorinsky pointed out to me
21 that we're missing what could be an important part,
22 which are the public comments. We ought to hear what
23 other people have had to say about it.

24 MR. VICKERY: The ones that we got, we did
25 get public comments. They mostly whined that the wind

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1 speeds are too high.

2 MEMBER BROWN: I read the public comments,
3 and that's fundamentally the crux of it, and they
4 thought they were, the numbers were --

5 CHAIR SHACK: Too high?

6 MEMBER BROWN: Too high, yes. That was
7 from the --

8 (Simultaneous speaking)

9 MEMBER BROWN: -- but the response was,
10 even though I'm not an educated, you know, numerical,
11 throw in the hand waving and the statistics, they seem
12 to be reasonable responses to the guidance. And
13 become, they stuck with their numbers.

14 MR. VICKERY: Yes, we put a fair bit, or
15 at least on the ARA's, we put a fair bit of effort
16 into the responses.

17 MR. SHUKLA: Selim, you want to go through
18 these?

19 MR. SANCAKTAR: I don't have anything
20 really, fundamentally new to add. If you want I can
21 go through my few slides but, as you wish.

22 CHAIR SHACK: So you felt there was really
23 nothing from the public comments that really affected
24 the outcome?

25 MR. SANCAKTAR: Right. In fact, my

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1 personal opinion was, they only deserve a paragraph
2 each, but I think we did a lot more than that.

3 MEMBER BROWN: Well you didn't have any
4 public, any --

5 MR. SANCAKTAR: We got four, we got two
6 public comments, really. One for --

7 MEMBER BROWN: Two of them were editorial,
8 the other two were complaining about, not complaining,
9 they articulated that the speeds were too high.

10 MR. SANCAKTAR: One was from a group
11 called Case, and they were really talking about
12 something totally different.

13 MR. VICKERY: Yes, they were out in left
14 field.

15 MR. SANCAKTAR: They were talking about,
16 out there about Turkey Point sites and, we couldn't
17 tell exactly how it related to this.

18 MEMBER STETKAR: I sort of read theirs,
19 but I couldn't understand whether their assertion was
20 that your predicted wind speeds for Turkey Point were
21 too high?

22 MR. SANCAKTAR: I couldn't understand what
23 the question was, that what --

24 (Simultaneous speaking)

25 MEMBER STETKAR: Yes, I got through that

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1 and I got really confused and I didn't, honestly go
2 back and re-read it again after I got better educated
3 on the analysis.

4 MR. SANCAKTAR: But we were very polite
5 and responsive.

6 MEMBER STETKAR: But you didn't have any
7 comments from any stakeholders --

8 MR. SANCAKTAR: Except Bechtel who, there
9 were two questions, Case and Bechtel. There were
10 other questions that were really internal, and they
11 were addressed.

12 So the Bechtel question was really posed
13 in a lot of detail. But in reality all it said was
14 there are a lot of uncertainties, yes, and then it
15 kind of said, well these are kind of conservative,
16 which, and then Peter wrote a pretty detailed response
17 for that. Other than that there was nothing else.

18 CHAIR SHACK: Any comments from the
19 gallery?

20 MEMBER BLEY: As comments go, I would like
21 to really thank you for a presentation that helped me
22 a lot, very professional and honest responses to us
23 officially, and very interesting.

24 MR. SANCAKTAR: I think this draws a line
25 in the sand. The question is, what other lines can be

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1 drawn and what's the conflict level, in general? But
2 I think what Peter did was scientifically very honest,
3 and he explained it well, I think.

4 And it is really pretty much at a state-
5 of-the-art level. There is no hocus-pocus in it. He
6 didn't try to make, cop out certain things or, you
7 know, introduce artificial ways to create things.

8 And so we are drawing a line. If people
9 are not satisfied with it, there's always a cop out,
10 you multiply something with a safety factor of 1.2,
11 1.5, 2, et cetera.

12 But speaking from a scientific point of
13 view, I think this is a pretty good work and probably,
14 in time, it will become more and more sophisticated.
15 Around ten years from now I'm sure there will be a lot
16 more added to it in various ways.

17 (Off the record comment)

18 MR. SIMIU: Also it's unfortunate that --

19 MEMBER STETKAR: My only concern is that
20 in ten years we don't have the perfect storm, and
21 suddenly find out that there's some fundamental errors
22 in the assumptions, or we didn't handle the
23 uncertainties correctly or things like that.

24 MEMBER BLEY: There is nothing we do that
25 doesn't have that possible.

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1 MEMBER STETKAR: That's absolutely true --
2 well, except for people going back and saying what we
3 should have learned from the data we had available.

4 MEMBER BLEY: But it seems they've done a
5 pretty good job of learning from that, near as I can
6 tell.

7 CHAIR SHACK: Yes, I mean, I think the
8 biggest assumptions you have is that, you know, the
9 process is going to remain stationary, it's not going
10 to change in time. You know, we've got the historical
11 database, I think we've worked that, as far as I can
12 tell, as rigorously as we can.

13 You know, there's that assumption in there
14 that, that's still going to be valid in the future,
15 but I don't know that there's a whole lot you can do
16 about that at the moment.

17 MEMBER BROWN: One observation is that
18 the numbers, previously you were using the tornado
19 standards, and the numbers now are bigger than the
20 tornado standards in some circumstances so it's become
21 more --

22 CHAIR SHACK: Conservative.

23 MEMBER BROWN: -- conservative relative to
24 how the new plants should apply those.

25 MEMBER BLEY: Except the reason this

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1 happened is because we changed the scaling on the
2 tornados, and that makes all the tornado events look
3 lower than they looked before.

4 MEMBER BLEY: I understand that but I --

5 MEMBER BROWN: So actually we're relaxing
6 it a bit.

7 MEMBER BLEY: Well, but you're boosting it
8 back up --

9 MEMBER BROWN: No.

10 MEMBER BLEY: -- the tornados were relaxed,
11 and now you've boosted it back up.

12 MEMBER BROWN: -- down here, and we're
13 catching at this point, instead of down here.

14 MEMBER BLEY: All right, I understand
15 we're going --

16 (Simultaneous speaking)

17 MEMBER BROWN: One other observation from
18 an uneducated, since I don't have all the statistical
19 stuff that you guys do is that, you take this
20 information, you come up with impacts and energies and
21 then those have other factors applied to them by the
22 designers.

23 MEMBER BLEY: Oh, yes.

24 MEMBER BROWN: So that the margin of error
25 it's like, when you look at standards for bridges, you

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1 know, all of a sudden you start looking at them, gee
2 they've multiplied everything by two by the time they
3 finish the struts and the other things that they've
4 got to do to make sure the bridges hold up.

5 So I was comfortable with it, and I don't
6 have the expertise that anybody else does, it just
7 sounded like, technically it sounded like a reasonable
8 story.

9 And it was definitely not a relaxation,
10 relaxation, relaxation of anything, because the
11 numbers were fairly large, for a reason, based on, you
12 know, best data we have.

13 CHAIR SHACK: Yes, as I said, I think it's
14 a --

15 MEMBER BROWN: And if John would have told
16 me before when I'd been accused of wanting being too
17 deterministic, how can you not, risk-informed approach
18 well, gee Barney, you didn't protect for meteorites
19 hitting the plant.

20 MR. SANCAKTAR: No, no -

21 MEMBER BROWN: I'm just, don't beat me up
22 right now. Just wait until later.

23 (Laughter)

24 MEMBER STETKAR: The frequency of a 10^{-7}
25 220 mile an hour three-second peak gust wind speed you

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1 need is smaller than the frequency of a one-meter
2 meteorite hitting a 1-acre spot and being distributed
3 around the United States. It's --

4 (Simultaneous speaking)

5 (Laughter)

6 MEMBER BROWN: I would be overwhelmed
7 rapidly here, with my qualitative subjective thought
8 processes.

9 CHAIR SHACK: Well if there are no further
10 questions or comments, I think we'll adjourn.

11 MEMBER STETKAR: And I don't think we need
12 to bring this to the full committee --

13 CHAIR SHACK: Close the record.

14 (Whereupon, the meeting in the above-
15 entitled matter was concluded at 4:38 p.m.)

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Regulatory Guide 1.221 "Design-Basis Hurricane and Hurricane Missiles for Nuclear Power Plants"

August 18, 2011

**A Presentation to Advisory Committee
on Reactor Safeguards
Regulatory Policies & Practices Subcommittee**



Presentation Outline

- Regulatory Basis. History of Extreme Wind
Regulatory Guidance
Brad Harvey, NRO
- Regulatory Guide 1.221
Selim Sancaktar, RES
- NUREG/CR-7005 Hurricane Wind Speeds
Peter Vickery, ARA
- NUREG/CR-7004 Hurricane Missiles
Emil Simiu, NIST
- Public Comments on Regulatory Guide
Selim Sancaktar, RES

Regulatory Basis and the History of Extreme Wind Regulatory Guidance

Brad Harvey
NRC Office of New Reactors

Presentation Outline

- Regulatory Basis
- History of Extreme Wind Regulatory Guidance
 - Design Basis Wind Load Criteria
 - History of Design Basis Tornado Wind Speeds
 - RG 1.76 (WASH-1300)
 - Staff Interim Position (NUREG/CR-4461)
 - SECY 93-087 (NUREG/CR-4461)
 - SECY 04-0200
 - DG-1143 (NUREG/CR-4461, Rev. 1)
 - RG 1.76 (NUREG/CR-4461, Rev. 2)
 - Why a New Regulatory Guide on Hurricanes

Regulatory Basis

- Appendix A to 10 CFR Part 50
 - GDC 2: *Design bases for protection against natural phenomena*
 - SSCs important to safety shall be designed to withstand the effects of natural phenomena such as ... tornadoes, hurricanes ... without loss of capability to perform their safety functions.
 - The design bases for these SSCs shall reflect appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated ...

Regulatory Basis

- Subpart B to 10 CFR Part 100
 - 10 CFR 100.20(c)(2)
 - Meteorological characteristics of the site that are necessary for safety analysis or that may have an impact upon plant design (such as maximum probable wind speed and precipitation) must be identified and characterized.

Design Basis Wind Load Criteria

Type of Load	Site Parameter/ Characteristic	Exceedance Frequency	ACI 349-97 Load Combinations and Factors
A <u>severe environmental load</u> that could infrequently be encountered during the plant life	Operating Basis Wind	10^{-2} per year	$U = 1.4D + 1.4F + 1.7L + 1.7H + 1.7W + 1.7R_o$
An <u>extreme environmental load</u> that is credible but highly improbable	Design Basis Tornado	10^{-7} per year	$U = D + F + L + H + T_o + R_o + W_t$

Combined Tornado Load Effects

$$W_t = W_p$$

$$W_t = W_w + 0.5W_p + W_m$$

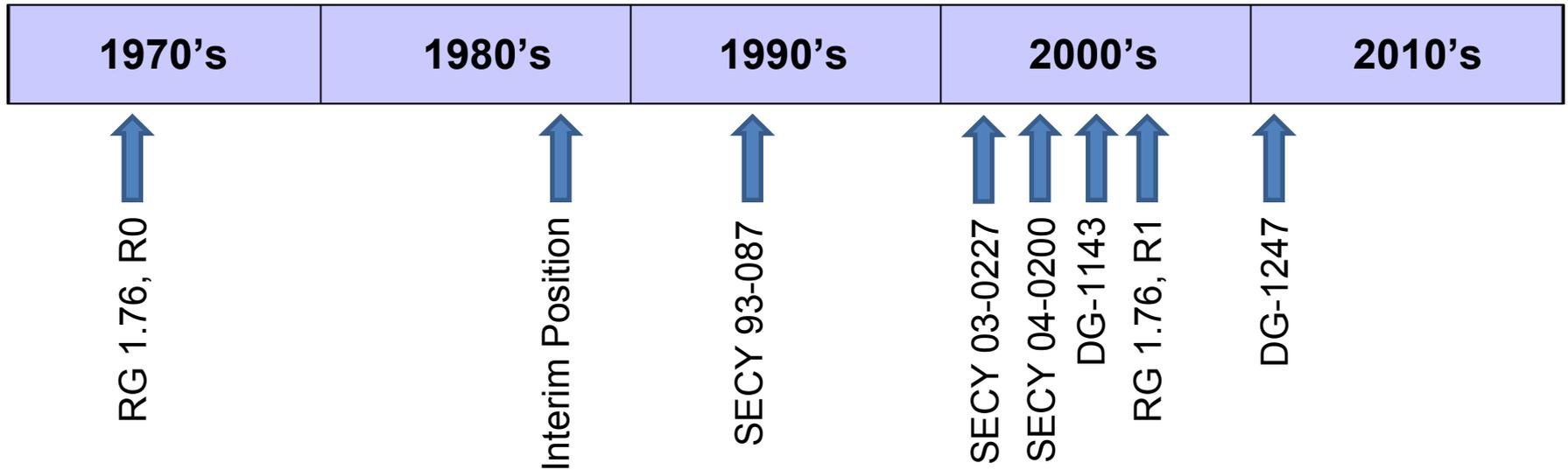
W_t = total tornado load

W_w = load from tornado wind effect

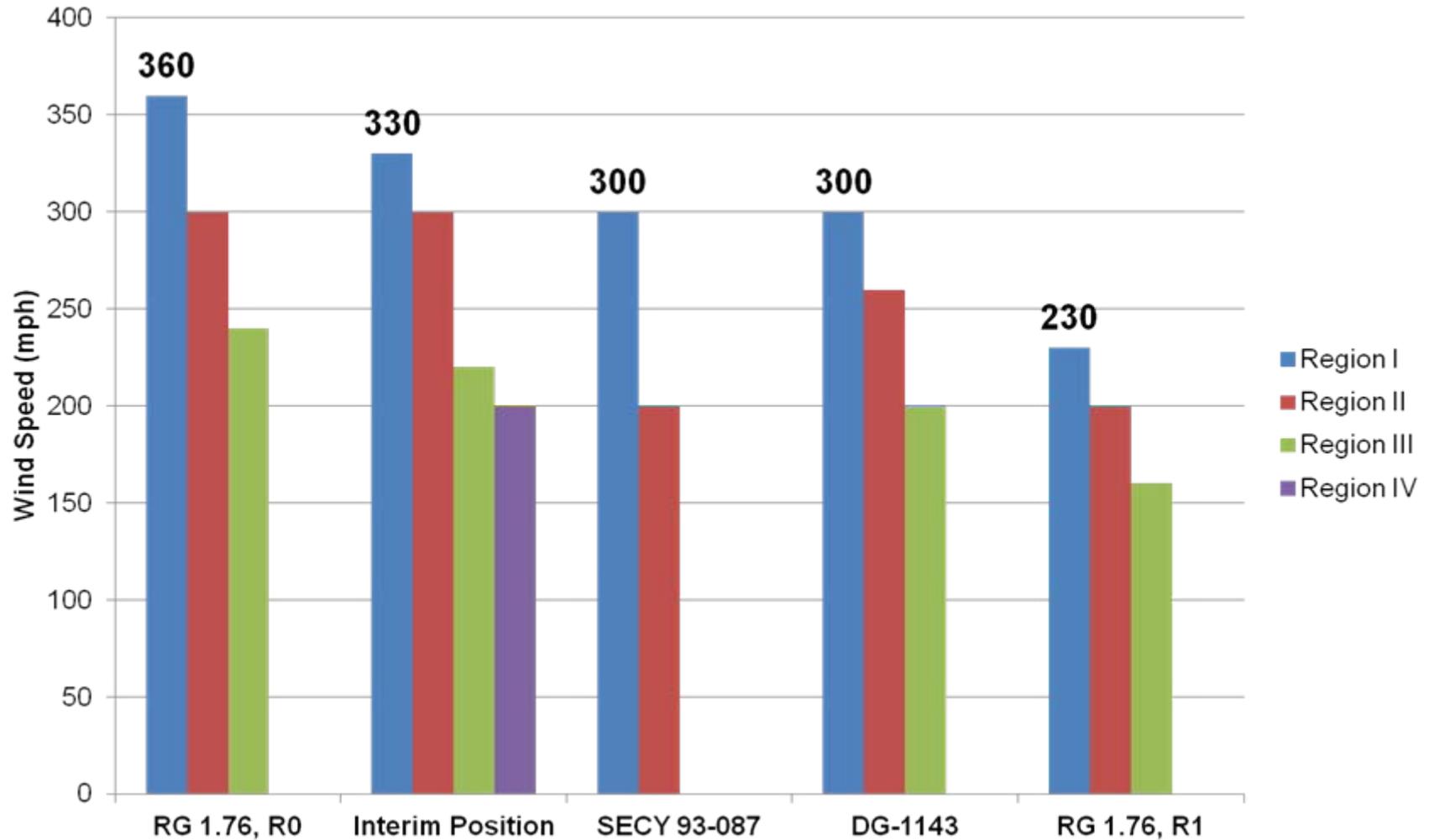
W_p = load from tornado atmospheric pressure change effect

W_m = load from tornado missile impact effect

History of Extreme Wind Regulatory Guidance



History of Design Basis Tornado Wind Speeds



Tornado Model

$$P(u \geq u_o) = P \times P(u \geq u_o |s) = 10^{-7} \text{ /yr}$$

$$P = A_t / (N A_r); \quad P(u \geq u_o |s) = A_{u \geq u_o} / A_t$$

$P(u \geq u_o)$ is the probability of the wind speed, u , exceeding some value u_o

P is the probability (per year) that a tornado will strike a particular location

$P(u \geq u_o |s)$ is the conditional probability that the wind speed u will exceed u_o , assuming that a tornado strike, s , occurs

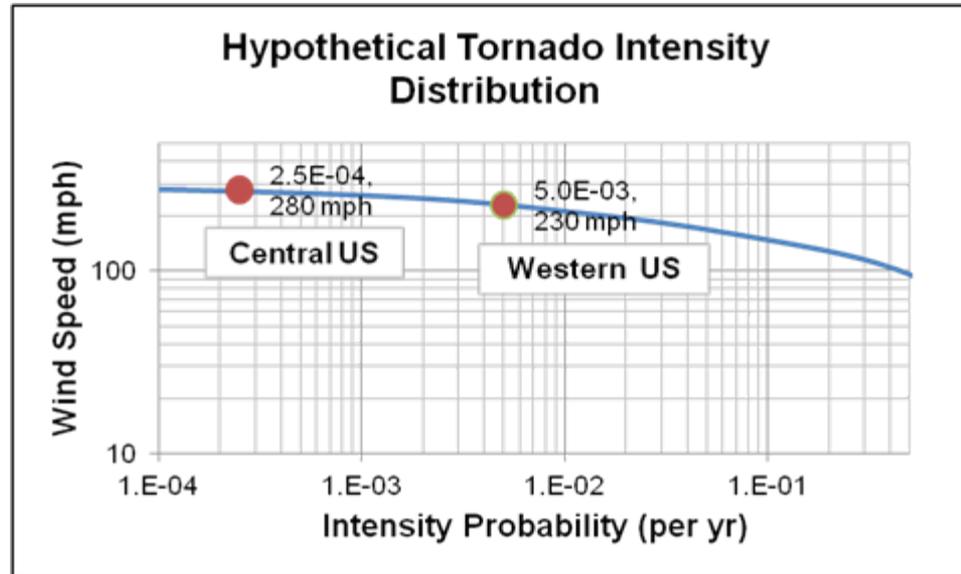
A_t is the total area impacted by tornadoes in the region of interest, A_r

N is the number of years of tornado records

$A_{u \geq u_o}$ is the total area impacted by wind speeds greater than u_o

Tornado Model

$$P(u \geq u_0) = P \times P(u \geq u_0 | s) = 10^{-7} \text{ /yr}$$



Location	Strike Probability P	Conditional Probability P(u ≥ u ₀ / s)	Wind Speed u ₀
Central US	4.0 x 10 ⁻⁴ per yr	2.5 x 10 ⁻⁴ per yr	280 mph
Western US	0.2 x 10 ⁻⁴ per yr	50 x 10 ⁻⁴ per yr	230 mph

Pressure Drop and Rate of Pressure Drop

- The pressure drop Δp within the tornado is a function of the tornado maximum rotational speed V_{rm}

$$\Delta p = \rho V_{rm}^2$$

- The rate of the pressure drop dp/dt is a function of the pressure drop Δp , the radius of the tornado R_m , and the tornado's translational speed V_t

$$(dp/dt) = \left(V_t / R_m \right) \Delta p$$

- The radius of the tornado (where the maximum rotational speed occurs) is assumed to be 150 ft
- The translational speed is assumed to be 1/5th of the tornado's maximum speed

F-Scale for Tornado Damage

F Number	Wind Speed (mph)	Potential Damage
	Fastest ¼ Mile	
0	40-72	
1	73-112	
2	113-157	
3	158-207	
4	208-260	
5	261-318	

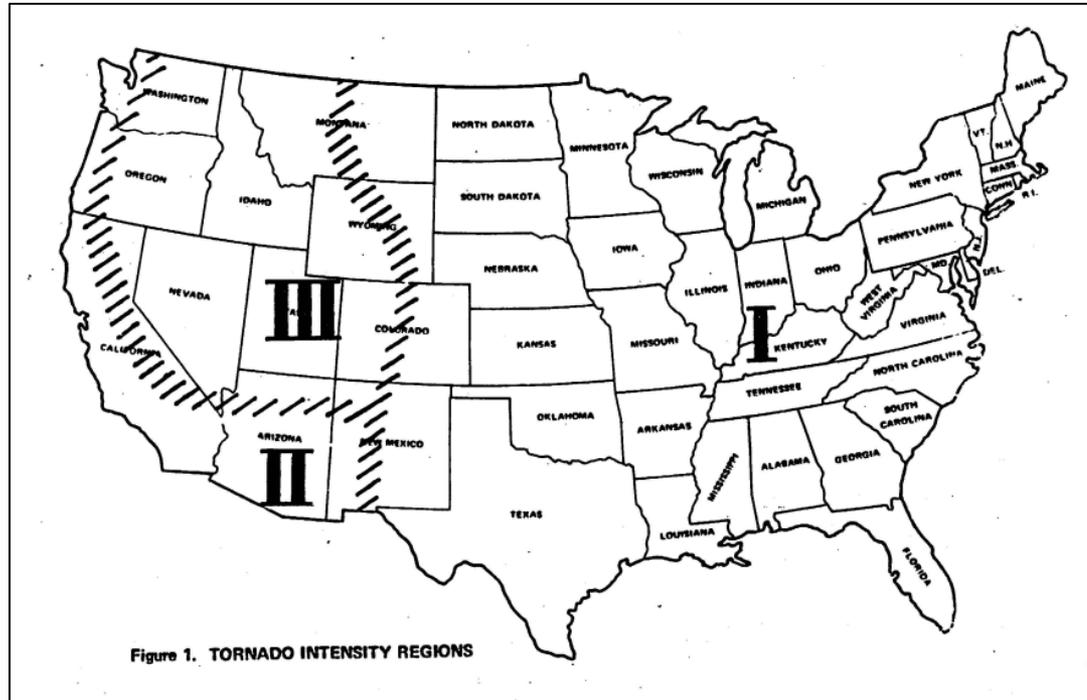
(a) Wind speed estimates based on observed damage

RG 1.76, Revision 0

(April 1974)

- *Design Basis Tornado for Nuclear Power Plants*
 - WASH-1300, *Technical Basis for Interim Regional Tornado Criteria (May 1974)*
 - Probability of occurrence of a tornado that exceeds the DBT should be 10^{-7} per year
 - 13 yrs of regional tornado frequency data
 - 2 yrs of tornado intensity data
 - Fujita tornado scale (F-Scale)
 - Maximum wind speed: 360 mph

RG 1.76, Revision 0



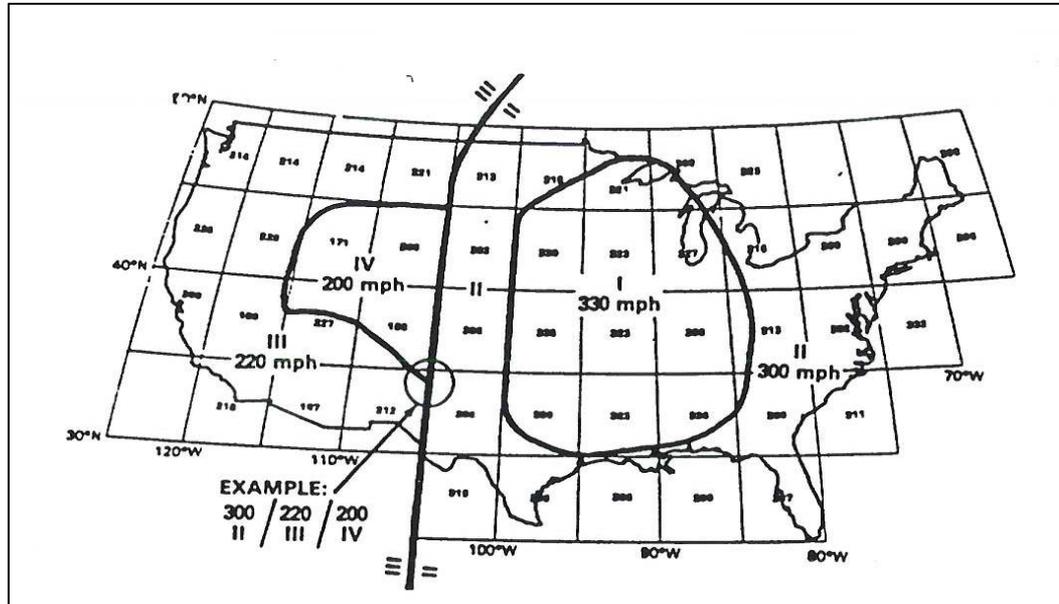
Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	360	3.0	2.0
II	300	2.25	1.2
III	240	1.5	0.6

Staff Interim Position

(March 1988)

- LS Rubenstein (NRC) letter to EE Kinter (ALWP Utility Steering Committee), *ALWR Design Basis Tornado*
 - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States* (May 1986)
 - 10^{-7} per year probability of occurrence at the upper 90% confidence level
 - 30 yrs of tornado frequency and intensity data
 - Fujita tornado scale (F-Scale)
 - Maximum wind speed: 330 mph

Staff Interim Position



Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	330	2.4	1.7
II	300	2.0	1.2
III	220	1.0	0.5
IV	200	0.9	0.3

SECY 93-087

(April 1993)

- *Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced LWR Designs*
 - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States* (May 1986)
 - Wind speed values associated with tornado having a mean recurrence interval of 10^{-7} per year
 - Maximum wind speed: 300 mph

SECY 03-0227

(December 2003)

- *Processing Applications for Early Site Permits*
 - RS-002 guidance for selecting site-specific tornado parameters
 - RG 1.76 (360 mph east of the Rocky Mts)
 - Staff interim position (330 mph east of the Rocky Mts)
 - Site-specific analysis
 - RS-002 siting guidance conflicted with SECY 93-087 certified standard reactor design guidance
 - 300 mph
 - Commission Directive
 1. Update guidance (e.g., RG 1.76) to reflect more recent tornado wind speed data
 2. Develop options in applying a risk-informed approach for selecting the design basis tornado

SECY 04-0200

(October 2004)

- *A Risk-Informed Approach to Defining the Design Basis Tornado for New Reactor Licensing*
 - Staff Suggested 3 Options
 1. Maintain SECY 93-087 definition a design basis tornado having a mean frequency of 10^{-7} per year
 2. Develop a risk-informed approach that would permit using a less conservative design basis tornado
 3. Relax the definition of the design basis tornado (e.g., initiating frequency $\approx 10^{-6}$ per year)
 - Commission Directive
 - Approved Option 1
 - Proceed with updating NUREG/CR-4461

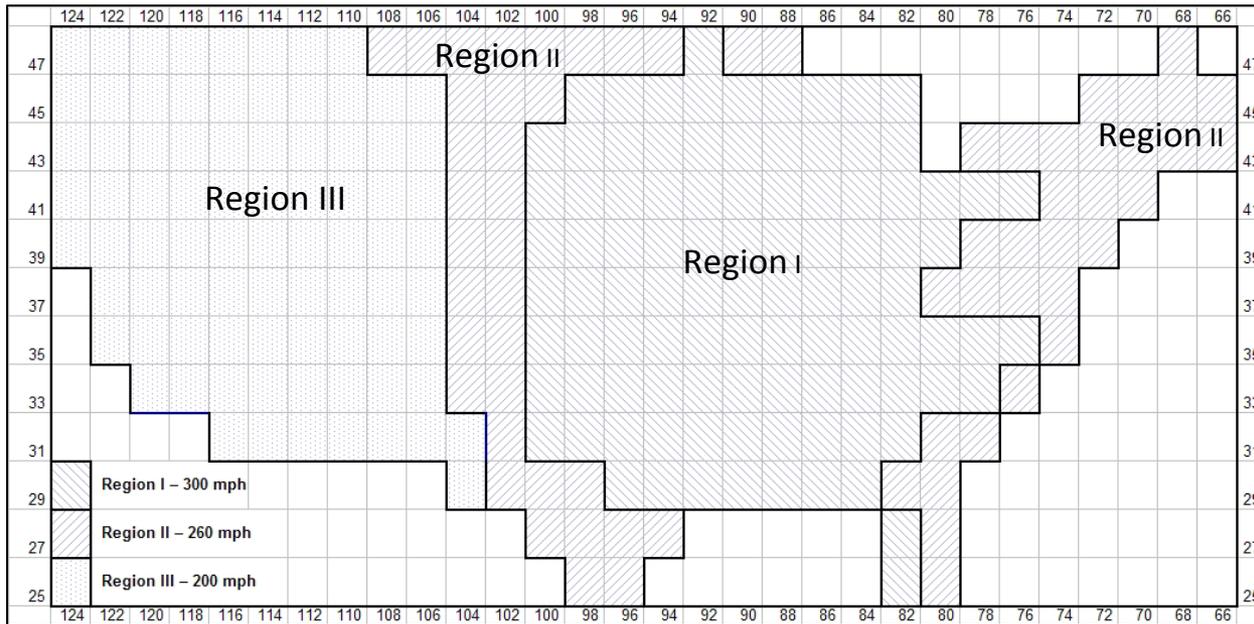
DG-1143 (draft R1 to RG 1.76)

(January 2006)

- *Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants*
 - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States*, Rev. 1 (Apr 2005)
 - Wind speed values associated with tornado having a mean recurrence interval of 10^{-7} per year
 - 53 yrs of tornado frequency and intensity data
 - Fujita tornado scale (F-Scale)
 - Finite dimensions of structures
 - Variation of wind speeds within the tornado path
 - Maximum wind speed: 300 mph



DG-1143 (draft R1 to RG 1.76)



Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	300	2.0	1.2
II	260	1.5	0.8
III	200	0.9	0.4

DG-1143 (draft R1 to RG 1.76)



Design Basis Missile Spectrum

Missile Type		Pipe	Auto	Sphere
Dimensions		6.6 in dia x 15 ft long	16.4 ft x 6.6 ft x 4.3 ft	1 inch dia
Mass		287 lb	4000 lb	0.147 lb
Horizontal Velocity	Region I	105 mph	116 mph	92 mph
	Region II	85 mph	101 mph	47 mph
	Region III	18 mph	76 mph	16 mph

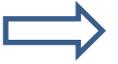
Vertical velocity is equal to 67% of the horizontal velocity

F-Scale vs. EF-Scale for Tornado Damage

FUJITA SCALE (F-Scale)			ENHANCED FUJITA SCALE (EF-Scale)	
F Number	Fastest ¼ Mile ^(a) (mph)	3 Sec Gust ^(a) (mph)	EF Number	3 Sec Gust ^(a) (mph)
0	40-72	45-78	0	65-85
1	73-112	79-117	1	86-110
2	113-157	118-161	2	111-135
3	158-207	162-209	3	136-165
4	208-260	210-261	4	166-200
5	261-318	262-317	5	Over 200

^(a) Wind speed estimates based on observed damage

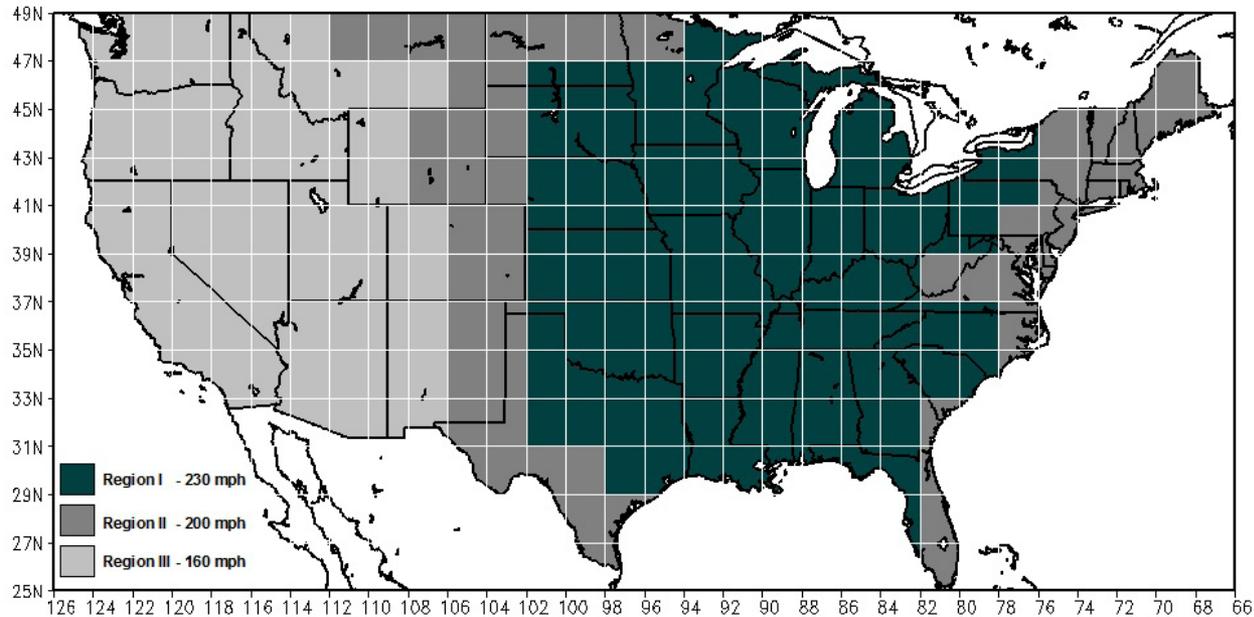
Revision 1 to RG 1.76



(March 2007)

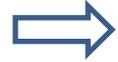
- *Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants*
 - NUREG/CR-4461, *Tornado Climatology of the Contiguous United States*, Rev. 2 (Feb 2007)
 - Wind speed values associated with tornado having a mean recurrence interval of 10^{-7} per year
 - 53 yrs of tornado frequency and intensity data
 - Enhanced F-scale
 - Finite dimensions of structures
 - Variation of wind speeds within the tornado path
 - Maximum wind speed: 230 mph

Revision 1 to RG 1.76



Tornado Region	Max Wind Speed (mph)	Pressure Drop (psi)	Rate of Pressure Drop (psi/sec)
I	230	1.2	0.5
II	200	0.9	0.4
III	160	0.6	0.2

Revision 1 to RG 1.76



Design Basis Missile Spectrum

Missile Type		Pipe	Auto	Sphere
Dimensions		6.6 in dia x 15 ft long	<u>Region I & II</u> 16.4 ft x 6.6 ft x 4.3 ft	1 inch dia
			<u>Region III</u> 14.9 ft x 5.6 ft x 4.9 ft	
Mass		287 lb	<u>Region I & II</u> 4000 lb	0.147 lb
			<u>Region III</u> 2595 lb	
Horizontal Velocity	Region I	92 mph	92 mph	18 mph
	Region II	76 mph	76 mph	16 mph
	Region III	54 mph	54 mph	13 mph

Vertical velocity is equal to 67% of the horizontal velocity

Height of auto is limited to 30 ft above the highest ground elevation within 0.5 mi

Why a New RG on Hurricanes?

- Public Comment on DG-1143:
 - The use of the EF scale would tend to place a greater emphasis on hurricane wind loads. At a very low probability of exceedance rate of 10^{-7} per year, hurricane wind speeds in the Atlantic and Gulf regions would approach or exceed tornado wind speeds.

Discussion/Committee Questions

Regulatory Guide 1.221

Dr. Selim Sancaktar
NRC Office of Nuclear Regulatory
Research



NRO User Need

- Regulatory Guide (RG) 1.221 is prepared in response to the NRO User Need Request (NRO-2007-003) for Design-Basis Hurricane Wind Speeds for new NPPs
- This RG is intended to supplement the existing Regulatory Guide 1.76 revision 1.

Background for the Hurricane RG User Need

- Recent work on tornadoes has led to the acceptance by the National Weather Service (NWS) of the Enhanced Fujita (EF) scale. Both the Enhanced Fujita scale and the original Fujita (F) scale assign wind speed ranges to degrees of damage caused by the tornado.
- The wind speed ranges assigned to a given degree of damage are lower for the Enhanced Fujita scale than for the original Fujita scale, since it was found that lower wind speeds could cause a given amount of structural damage than was thought when the Fujita scale was originally constructed. As a consequence, the NPP design-basis tornado wind speed, defined as the wind speed with a 1E-7 per year exceedance frequency, has been lowered.
- Based on the EF-Scale, the maximum design-basis tornado wind speed for any location in the United States is 230 mph.
- Based on the original F-Scale, the maximum design-basis tornado wind speed is 300 mph.
- The design basis tornado wind speeds given in Regulatory Guide 1.76, rev. 1 are based on the EF-Scale.

Background for the Hurricane RG User Need

- As a result of lowering the maximum design-basis tornado wind speed from 300 mph to 230 mph, the 1E-7 per year design-basis tornado wind speed may no longer bound the 1E-7 per year design-basis hurricane wind speed for plants situated along the Gulf, Atlantic, and Pacific coasts of the United States.
- Therefore, regulatory guidance may be needed to define 1E-7 per year design-basis hurricane wind speeds for new plants located along the Gulf, Atlantic, and Pacific coasts.

Project Scope Leading to RG 1.221

- RES commissioned two NUREG/CRs to recognized experts as technical support for the REG guide 1.221. The resulting reports are:
- NUREG/CR-7005: Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants
- NUREG/CR-7004: Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants

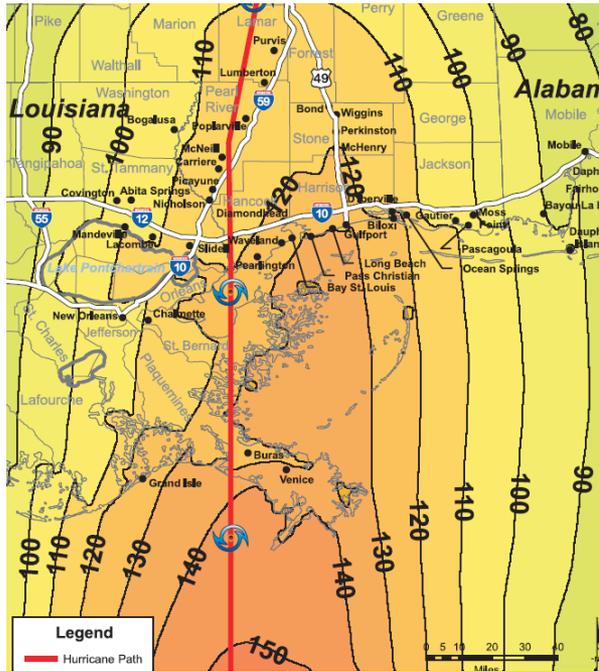
Project Scope Leading to RG 1.221

- A draft RG (DG-1247) was created and submitted for public comments, together with the NUREG/CRs.
- After the public comments are received, the three documents were finalized.
- RG1.221 is intended to complement RG 1.76 and has the same general structure as RG 1.76. The reg guide is intended for use by NRO for new plant applications.
- Draft RG, RG, the NUREG/CRs and the responses to public comments were provided to other cognizant NRC offices and their concurrences were obtained.

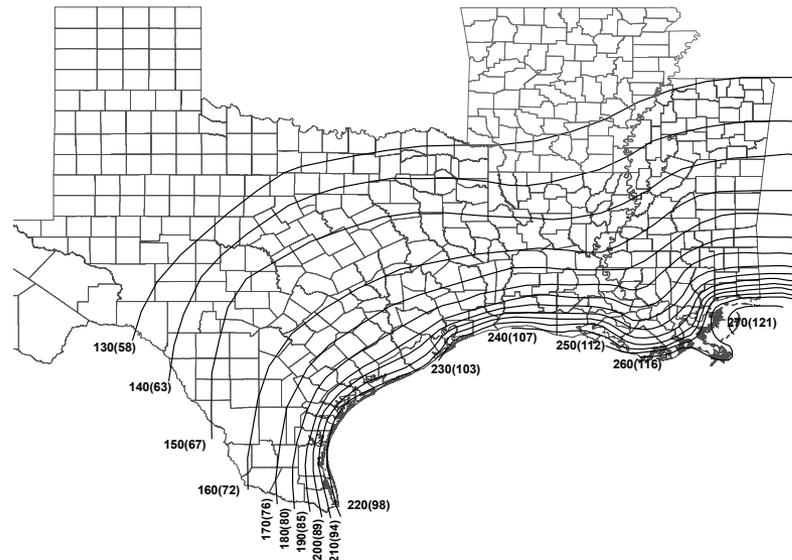
Supporting NUREG/CRs

- NUREG/CRs 7005 and 7004 are referred to as acceptable technical approaches that can be used by new reactor applicants.
- In the next part of the presentation, the two NUREG/CRs will be briefly discussed by their authors.

Technical Basis for Regulatory Guidance on Design-Basis Hurricane Wind Speeds for Nuclear Power Plants



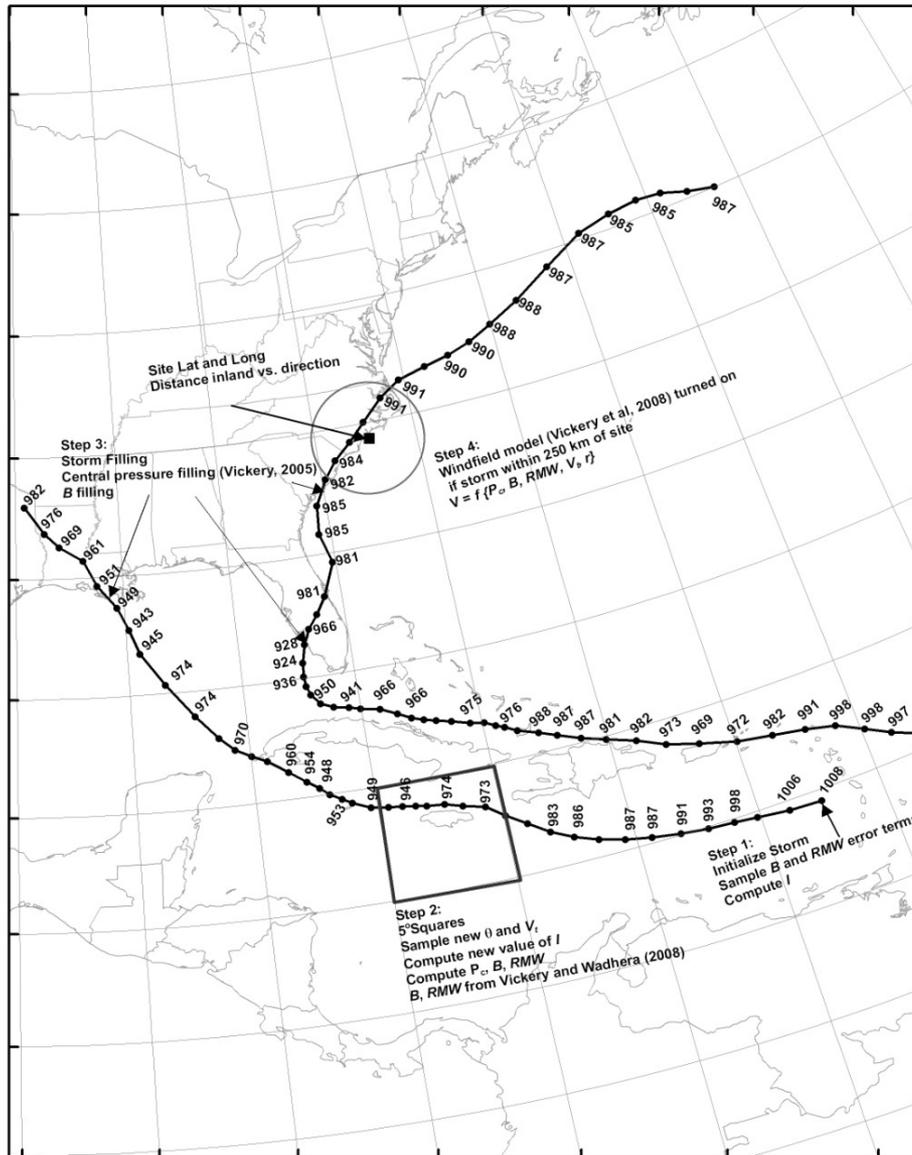
Peter J Vickery
Applied Research Associates, Inc
8537 Six Forks Rd, Suite 600
Raleigh, NC 27615



Overview

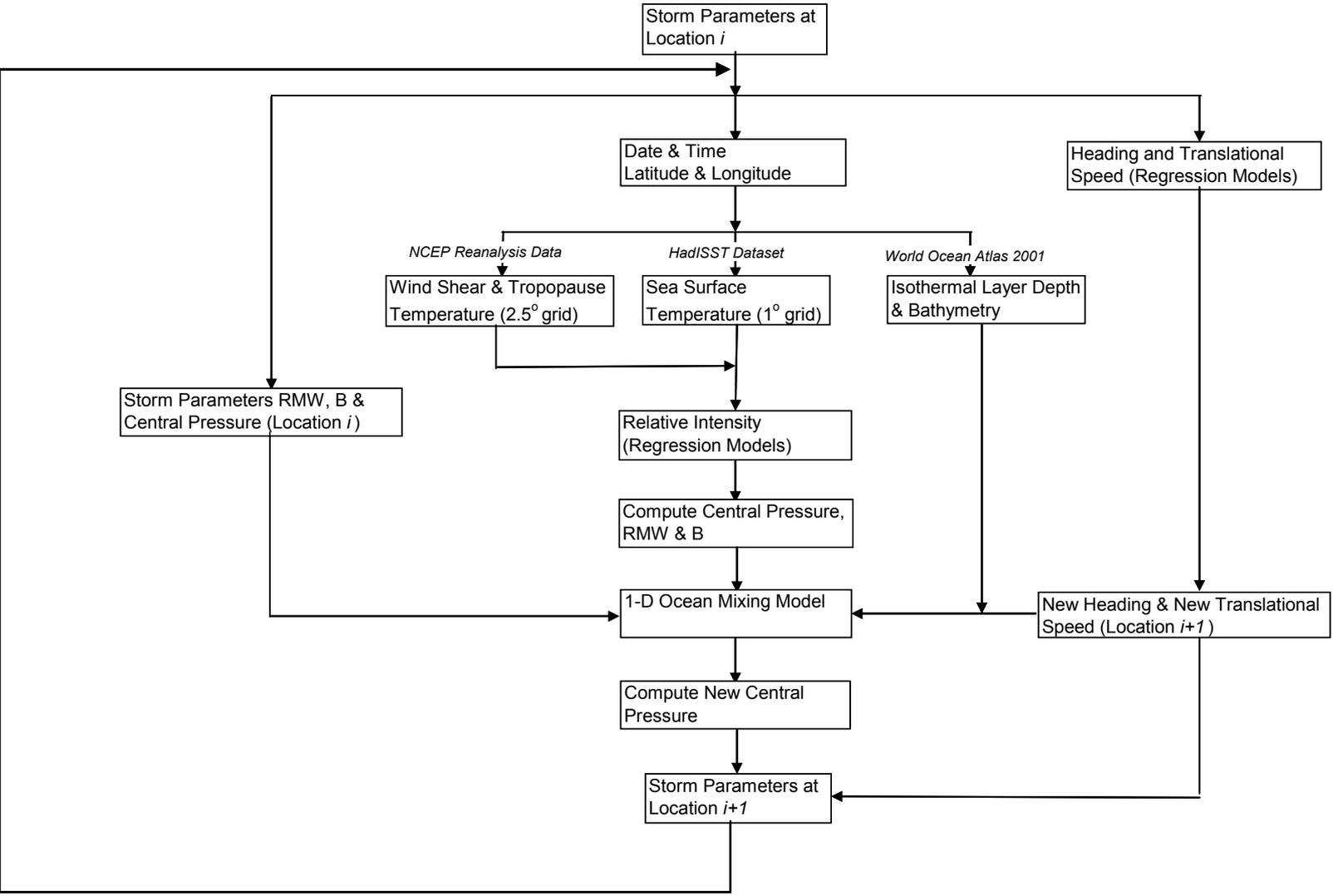
- Simulation Methodology Overview
 - B and RMW models
 - Hazard model validation
 - Model changes for 10^{-7} study
 - Wind Field Model
 - Sea surface drag coefficient
 - Hurricane boundary layer model
 - Validation examples
- 10^{-7} Study Simulation Methodology
 - Model changes
 - Wind Speed Maps
 - Summary

Simulation Approach and Flow Chart

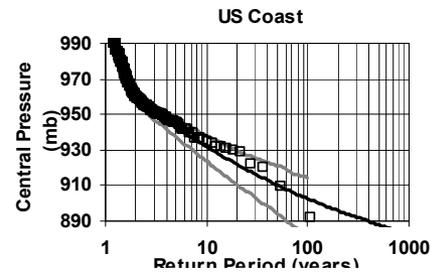
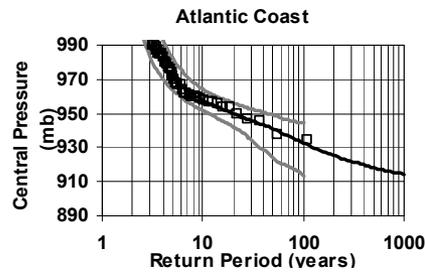
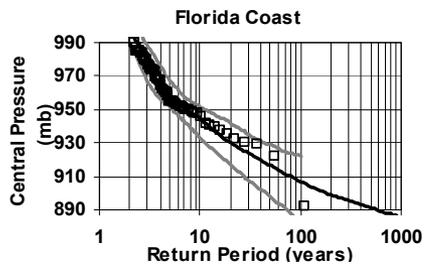
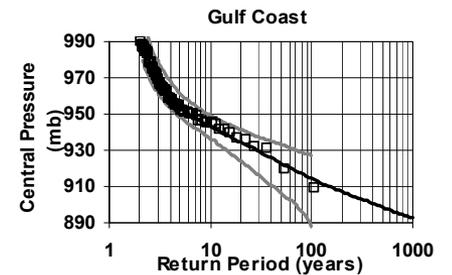
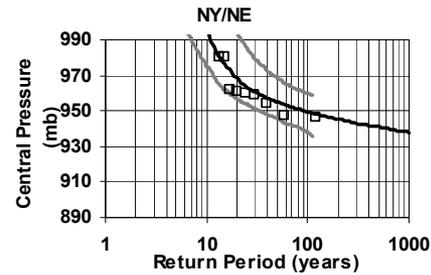
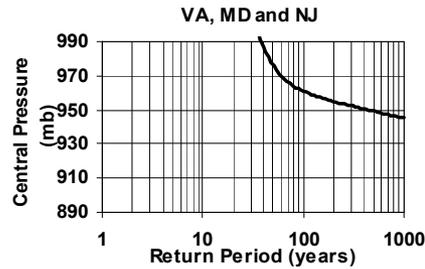
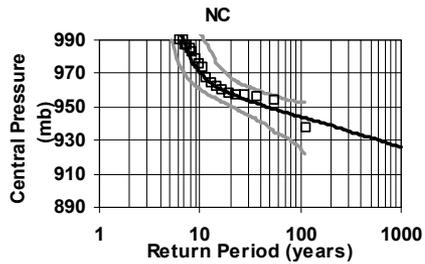
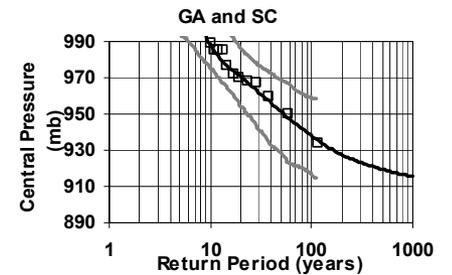
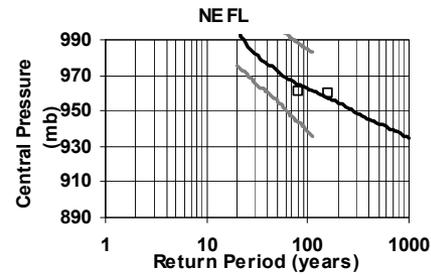
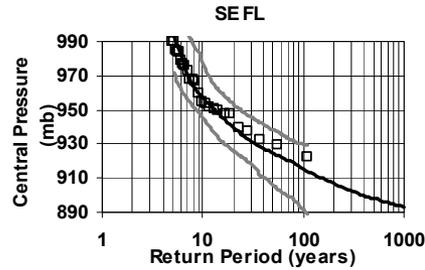
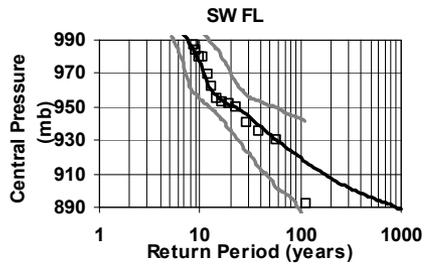
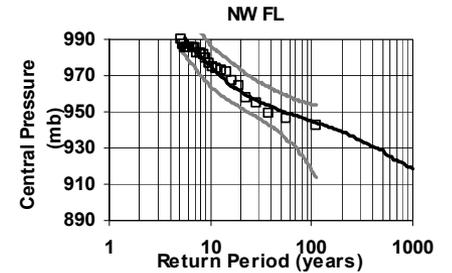
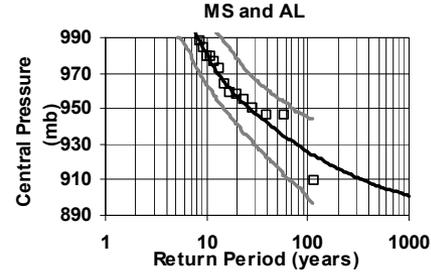
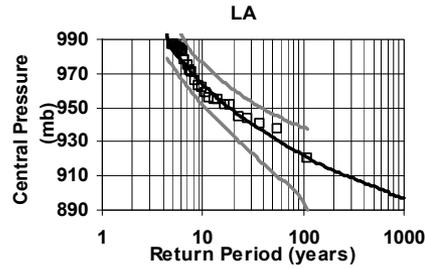
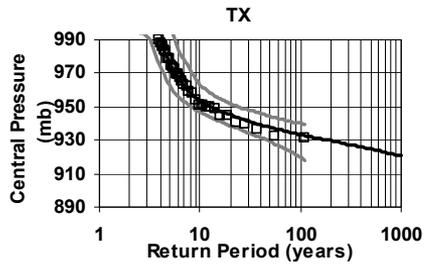


Track model uses historical data through 2007

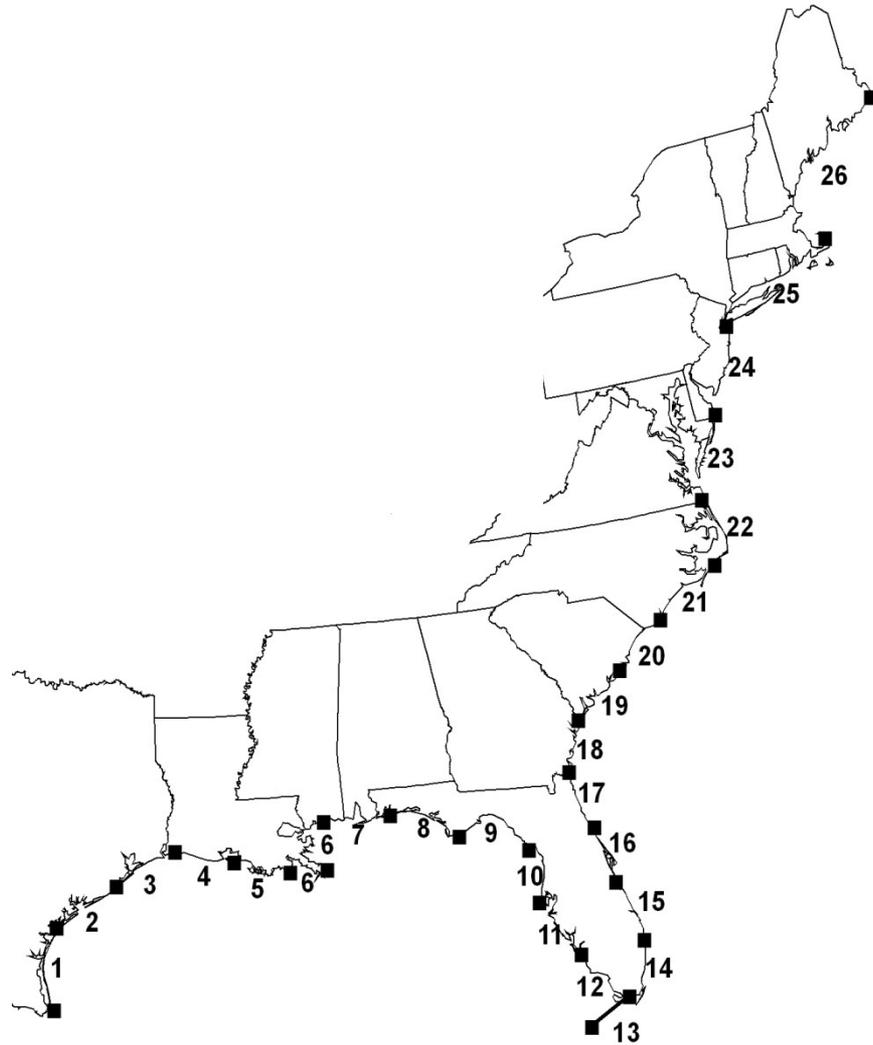
Simulation Approach and Flow Chart



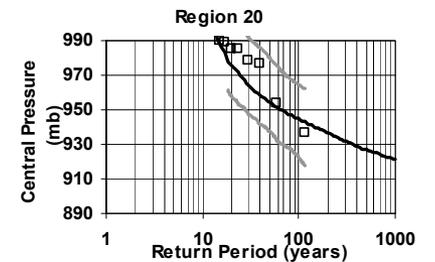
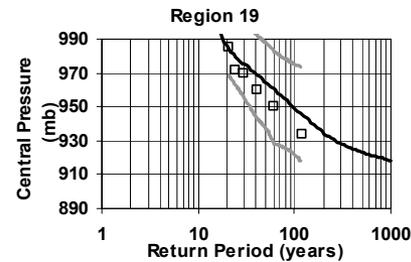
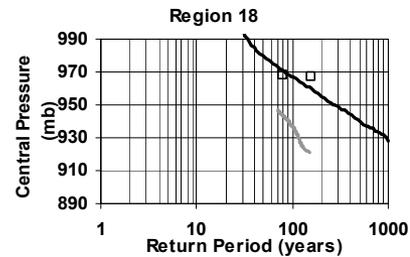
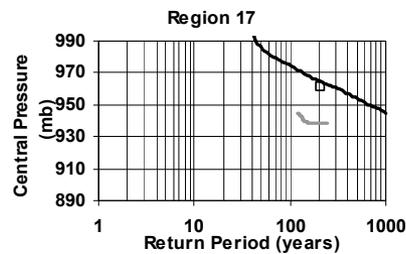
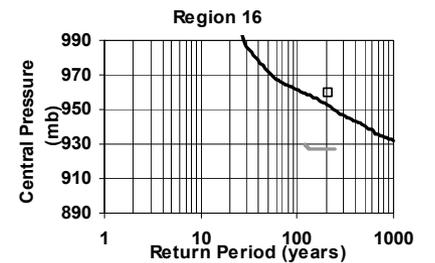
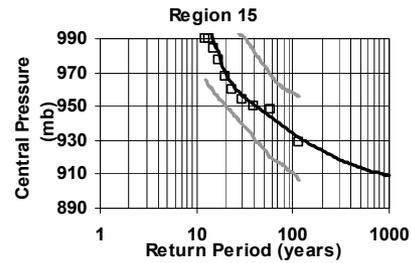
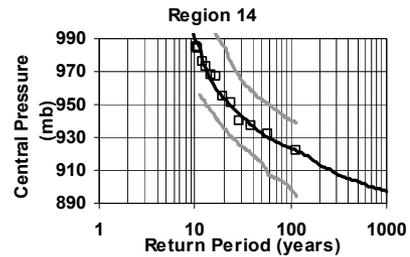
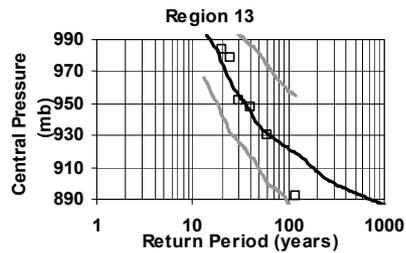
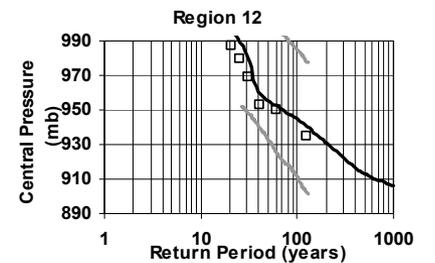
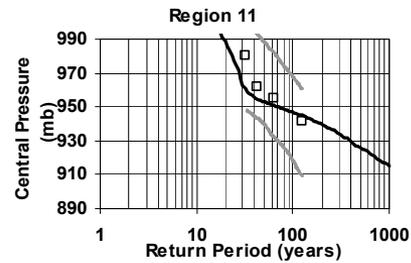
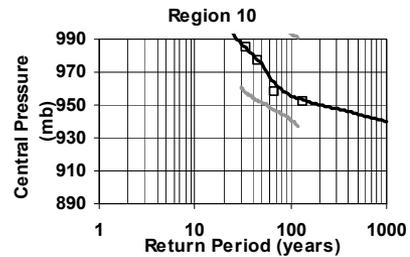
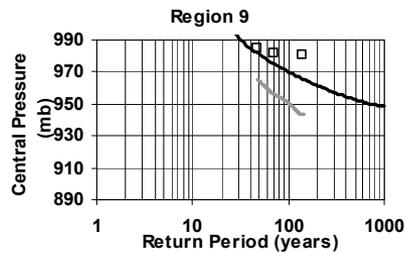
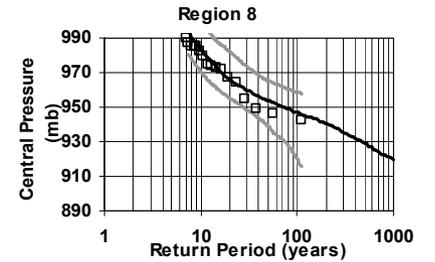
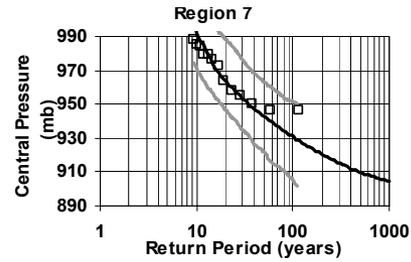
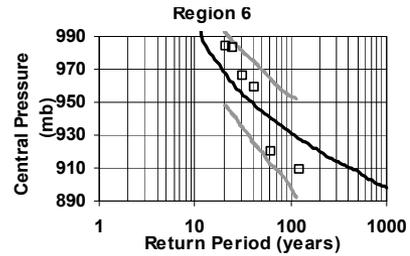
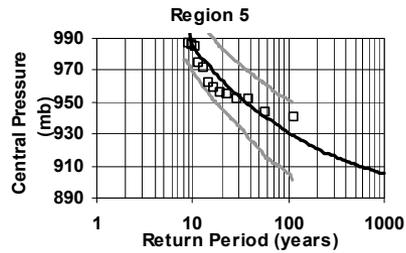
Landfall Pressures



Coastal Segments

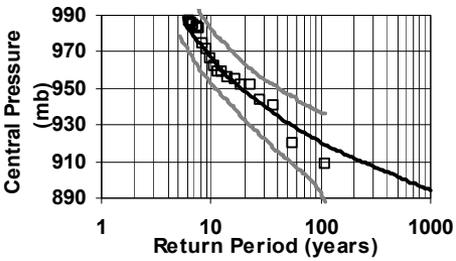


Landfall Pressures

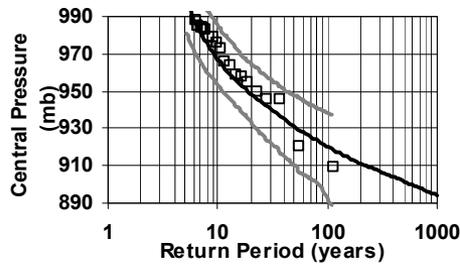


Landfall Pressures

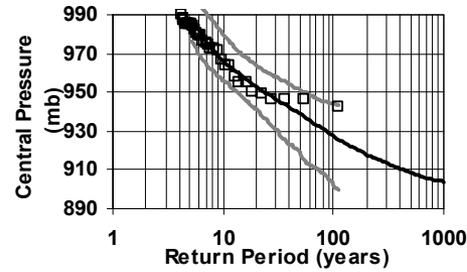
Regions 5 and 6



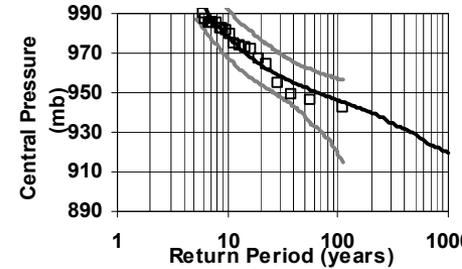
Regions 6 and 7



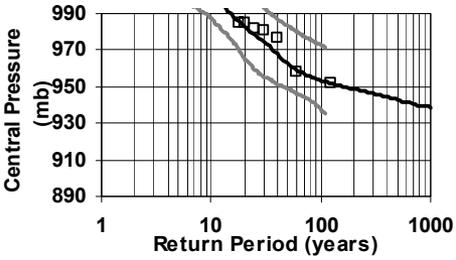
Regions 7 and 8



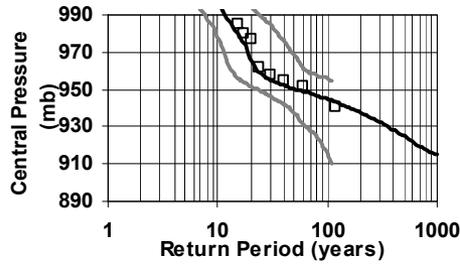
Regions 8 and 9



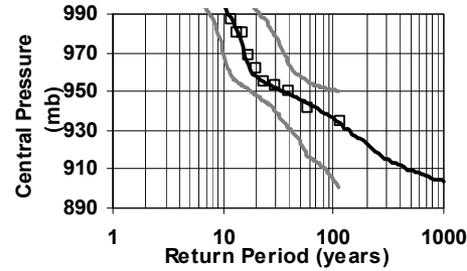
Regions 9 and 10



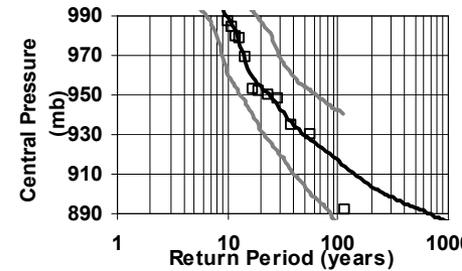
Regions 10 and 11



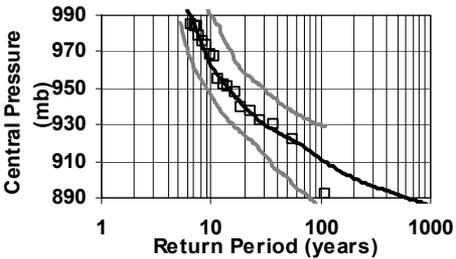
Regions 11 and 12



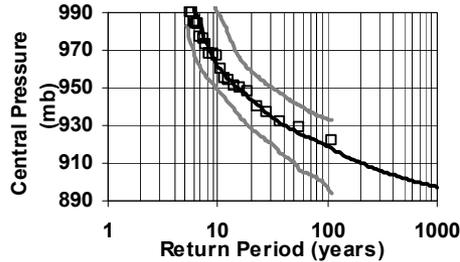
Regions 12 and 13



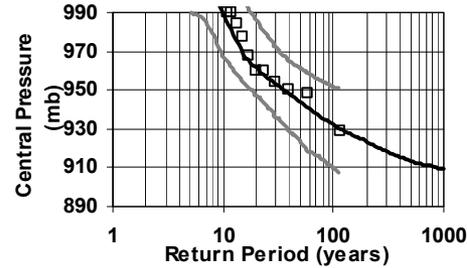
Regions 13 and 14



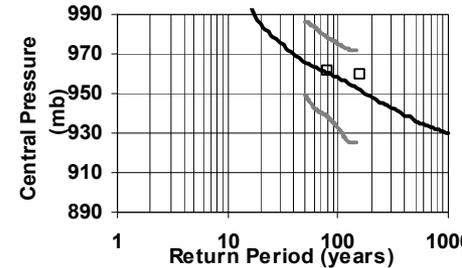
Regions 14 and 15



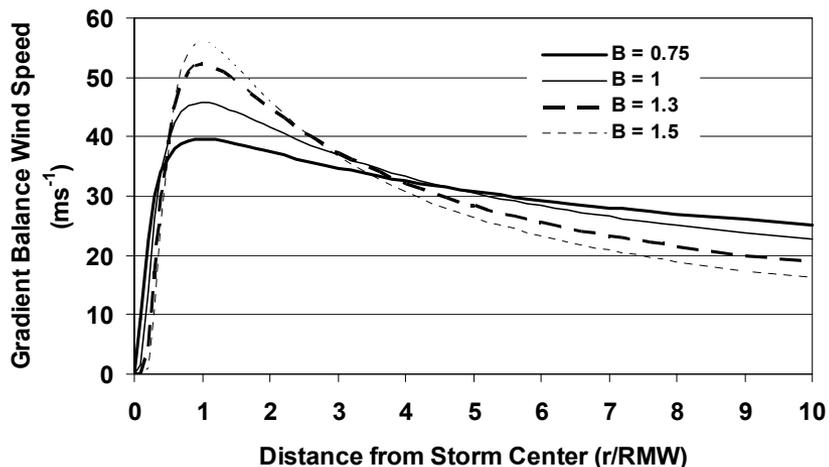
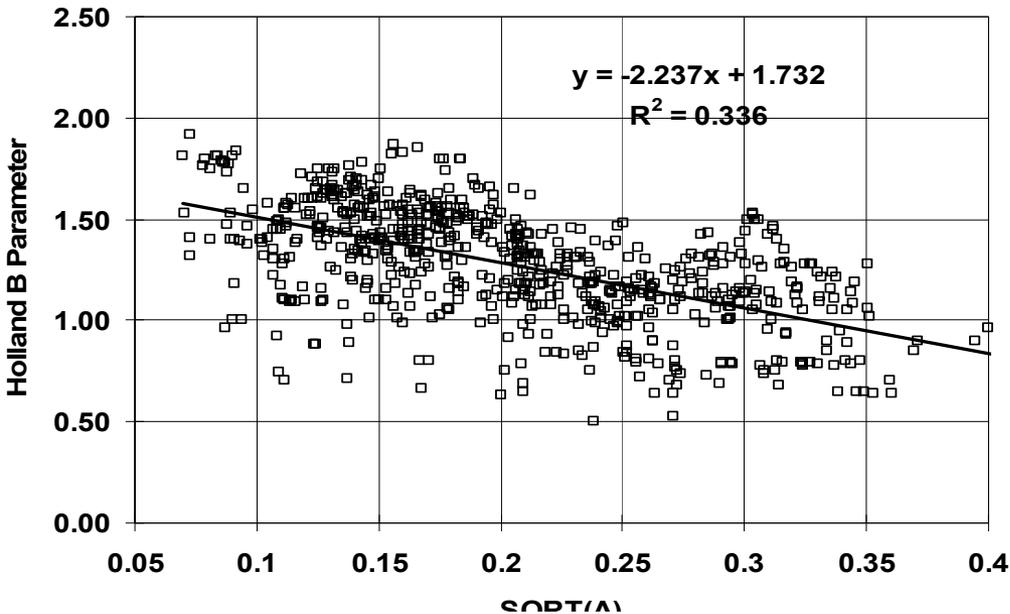
Regions 15 and 16



Regions 16 and 17



Holland B Parameter



- B estimates derived from upper level flight data and H*Wind snapshots of hurricane wind fields.
- B modeled as a function of A where

$$A = \frac{\text{RMW} \cdot f_c}{\sqrt{2R_d T_s \cdot \ln\left(1 + \frac{\Delta p}{p_c \cdot e}\right)}}$$

R_d is the gas constant for dry air, p_c is the central pressure, T_s is the sea surface temperature ($^{\circ}\text{C}$), Δp is central pressure difference, RMW is radius to maximum winds

Vickery and Wadhera (2008), "Statistical Models of Holland Pressure Profile Parameter and Radius to Maximum Winds of Hurricanes from Flight Level Pressure and H*Wind data", *Journal of Applied Meteorology and Climatology*, **47**,

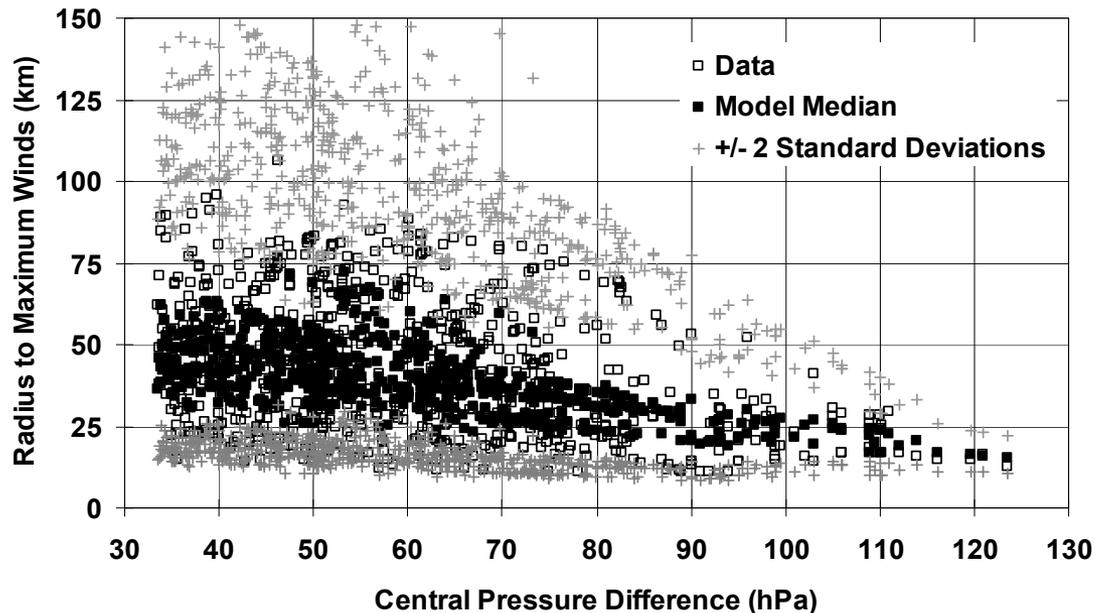
RMW Models

- Atlantic Region

$$\ln(RMW) = 3.015 - 6.291 \times 10^{-5} \Delta p^2 + 0.0337 \Psi + \varepsilon \quad r^2=0.297, \sigma_{\ln RMW}=0.441$$

Δp is central pressure difference, Ψ is the latitude and ε is the random error term. The error, $\sigma_{\ln RMW}$, is modeled in the form:

$$\begin{aligned} \sigma_{\ln RMW} &= 0.448 & \Delta p \leq 87 \text{ hPa} \\ \sigma_{\ln RMW} &= 1.137 - 0.00792 \Delta p & 87 \text{ hPa} \leq \Delta p \leq 120 \text{ hPa} \\ \sigma_{\ln RMW} &= 0.186 & \Delta p > 120 \text{ hPa} \end{aligned}$$



ARA Event Model Summary

- Hazard model developed/validated using data through 2007
- Simple ocean mixing model to limit intensity
- Calibrated to match historical record for the period 1900-2007
- Statistical models for *B* and *RMW*

Wind Field Model

Equations of Motion for Model Hurricane

$$\frac{d\vec{V}_s}{dt} + f|\vec{k} \times \vec{V}_s| = -\frac{1}{\rho} \nabla p + \nabla \cdot (K_H \nabla \vec{V}_s) - \frac{C_D}{h} |\vec{V}_s + \vec{V}_c| (\vec{V}_s + \vec{V}_c)$$

$$\frac{\partial p}{\partial r} = \frac{\Delta p B}{r} \left(\frac{R_{\max}}{r} \right)^B \exp \left(- \left(\frac{R_{\max}}{r} \right)^B \right)$$

Drag Coefficient over the Ocean

Powell, 1980

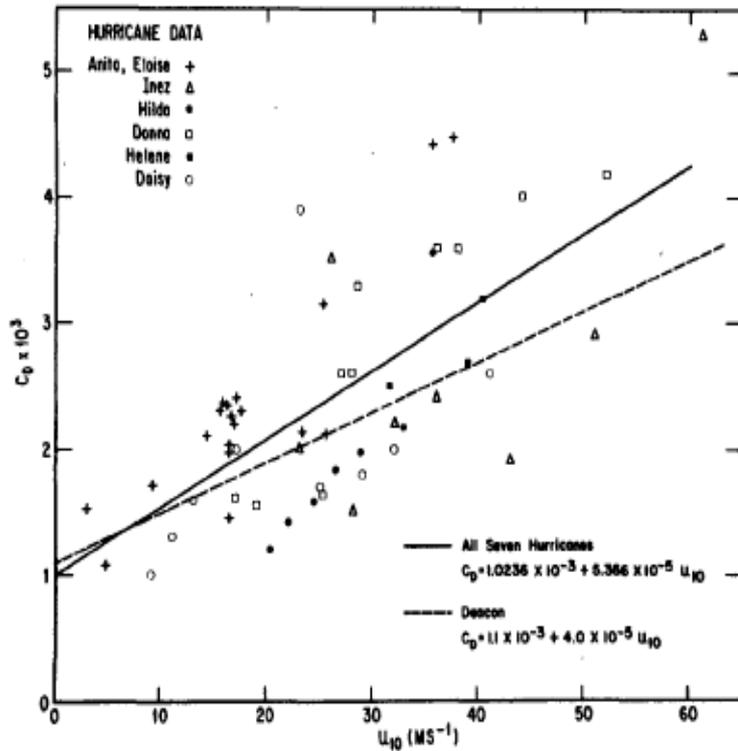
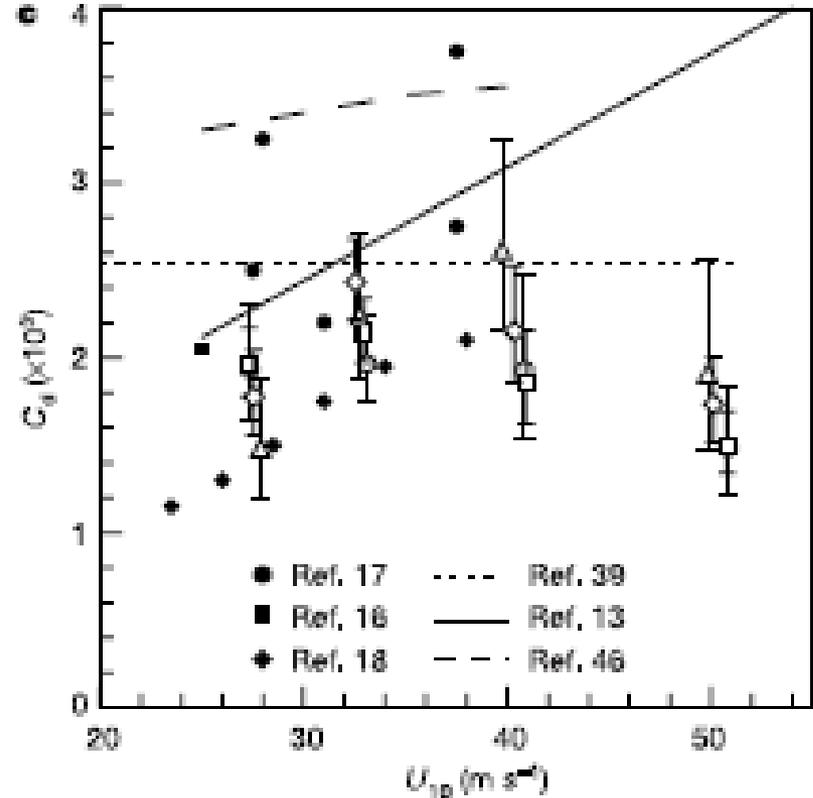


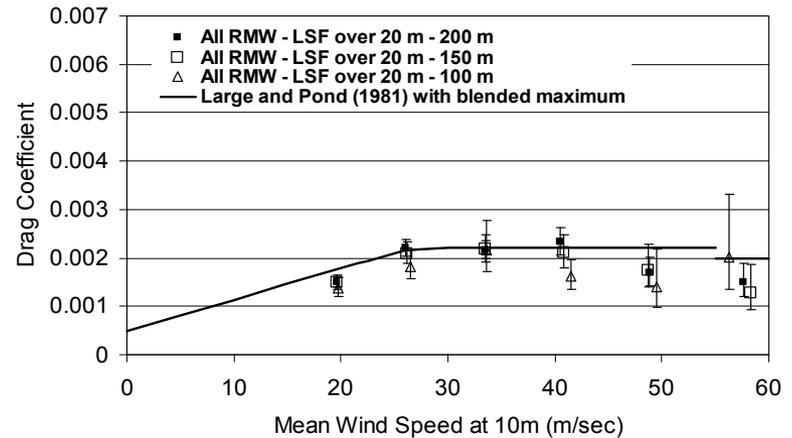
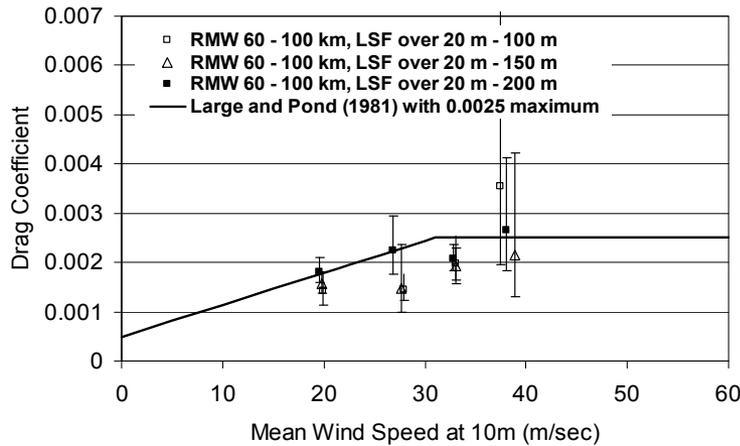
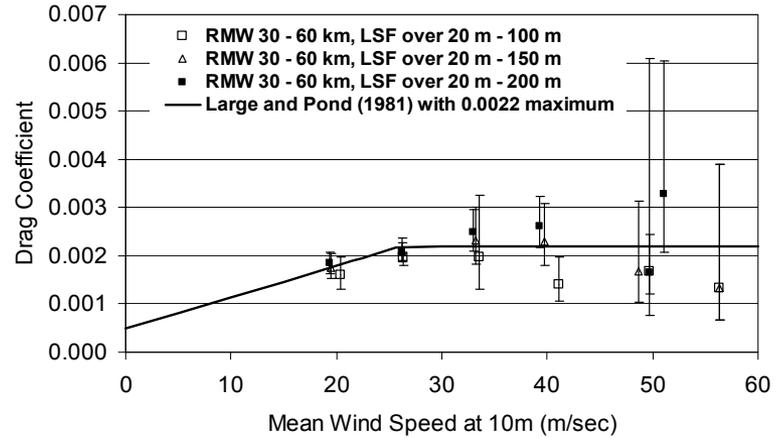
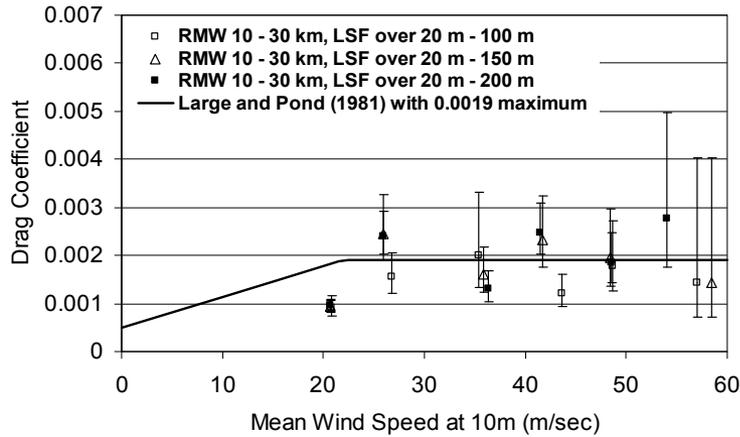
FIG. 5. Ten meter level neutral drag coefficient from several studies plotted versus wind speed.

Powell, et al, 2003

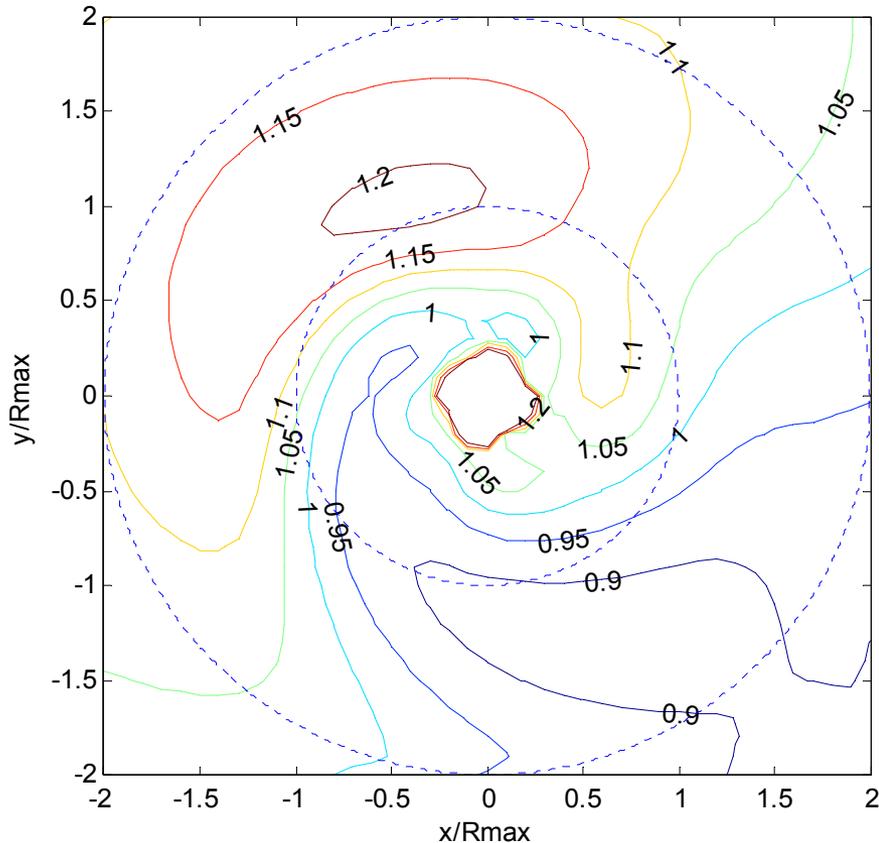


$$C_D (\text{open terrain}) = 0.00471$$

Sea Surface Drag Coefficient Model



Hurricane Jet Strength



Storm is moving towards top of page

- Jet Strength = Wind Speed at top of BL divided by gradient balance wind

$$\frac{d\vec{V}_s}{dt} + f \left| \vec{k} \times \vec{V}_s \right| = -\frac{1}{\rho} \nabla p$$

- Magnitude of jet strength similar to results from full 3D models

Hurricane Boundary Layer Model

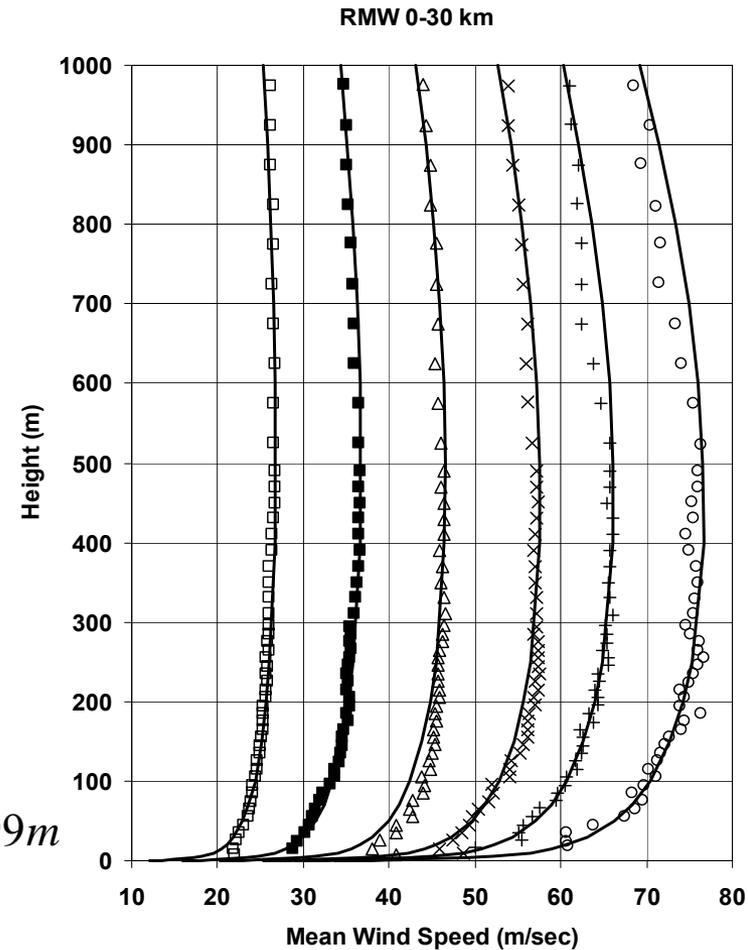
- Boundary Layer Model developed using Dropwindsonde data.
- Includes the radial variation of BL height
- Marine Boundary Layer Model given by:

$$U(z) = \frac{u_*}{k} \left[\ln\left(\frac{z}{z_o}\right) - a\left(\frac{z}{H^*}\right)^n \right]$$

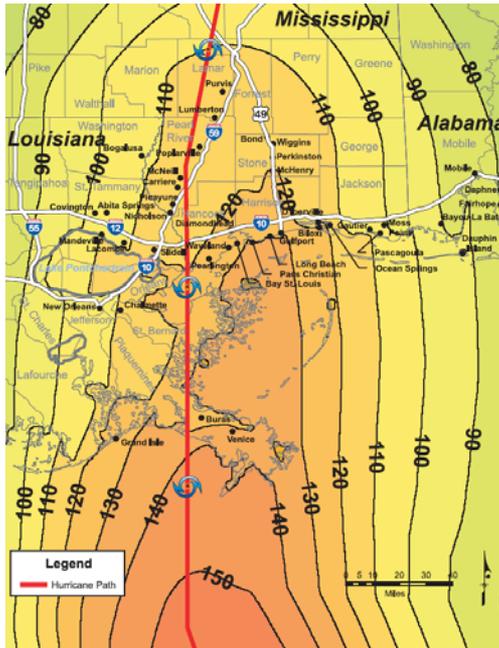
- Boundary layer Height given by:

$$H^* = 343.7 + 0.260 / I \quad r^2 = 0.75, \quad \sigma_e = 99m$$

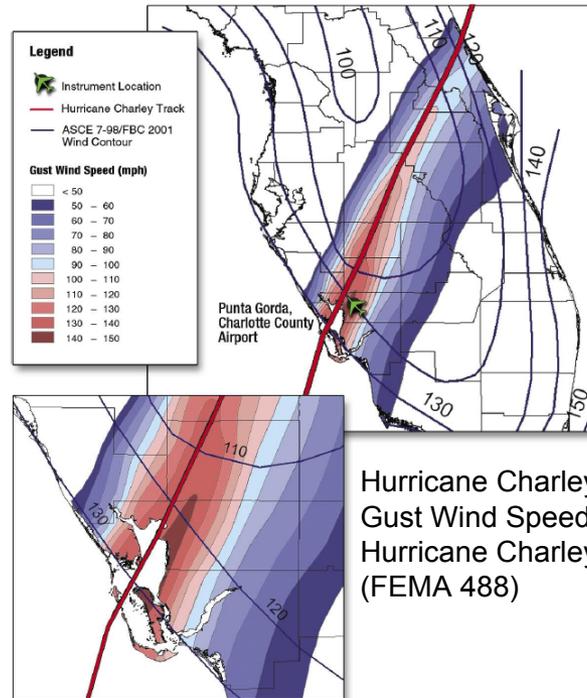
Vickery et al (2009), "A Hurricane Boundary Layer and Wind Field Model for Use in Engineering Applications", *Journal of Applied Meteorology and Climatology*, 2009, **48**, 381-405



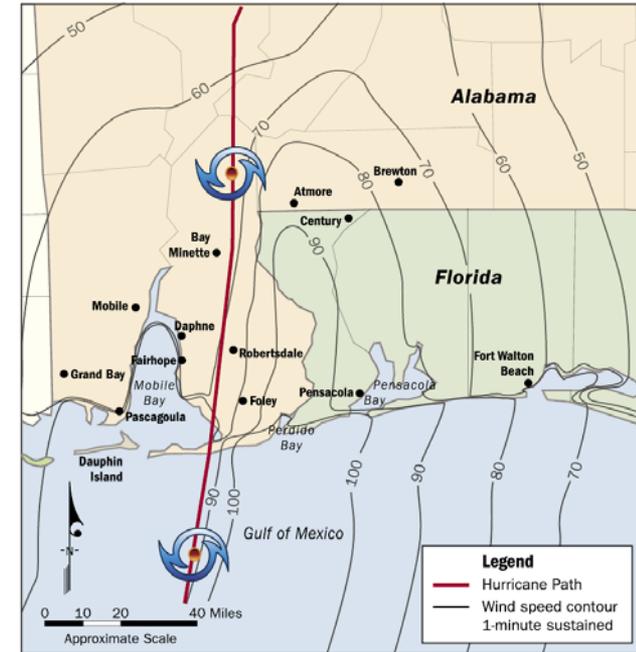
Example Wind Speed Validation Studies



Hurricane Katrina
Gust Wind Speeds
Hurricane Katrina MAT
(FEMA 549)



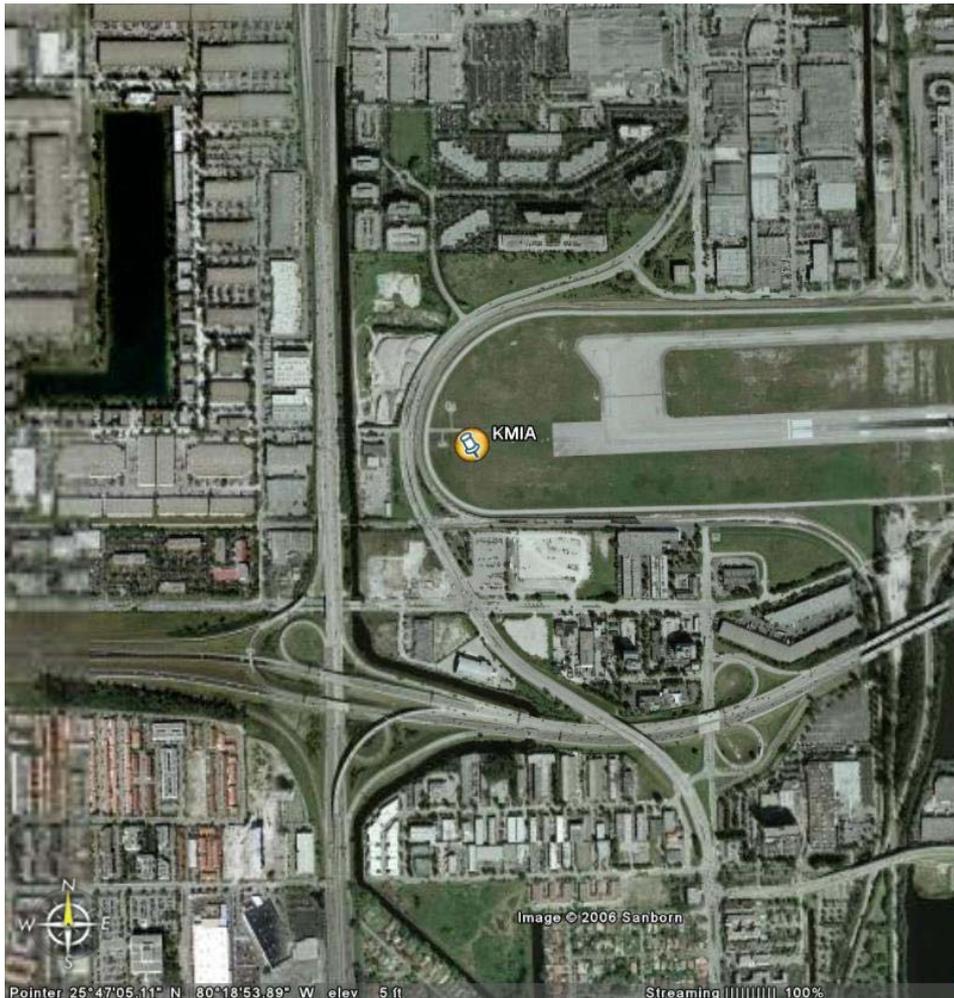
Hurricane Charley
Gust Wind Speeds
Hurricane Charley MAT
(FEMA 488)



Hurricane Ivan
One Minute Wind Speeds
Hurricane Ivan MAT
(FEMA 489)

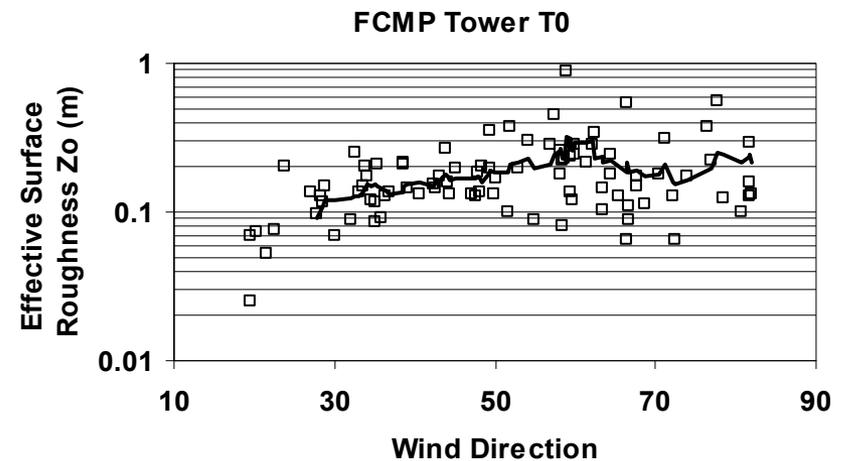
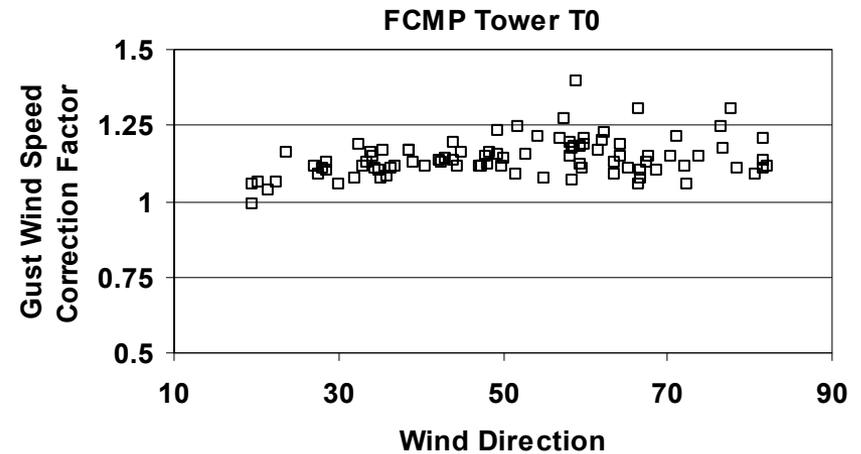
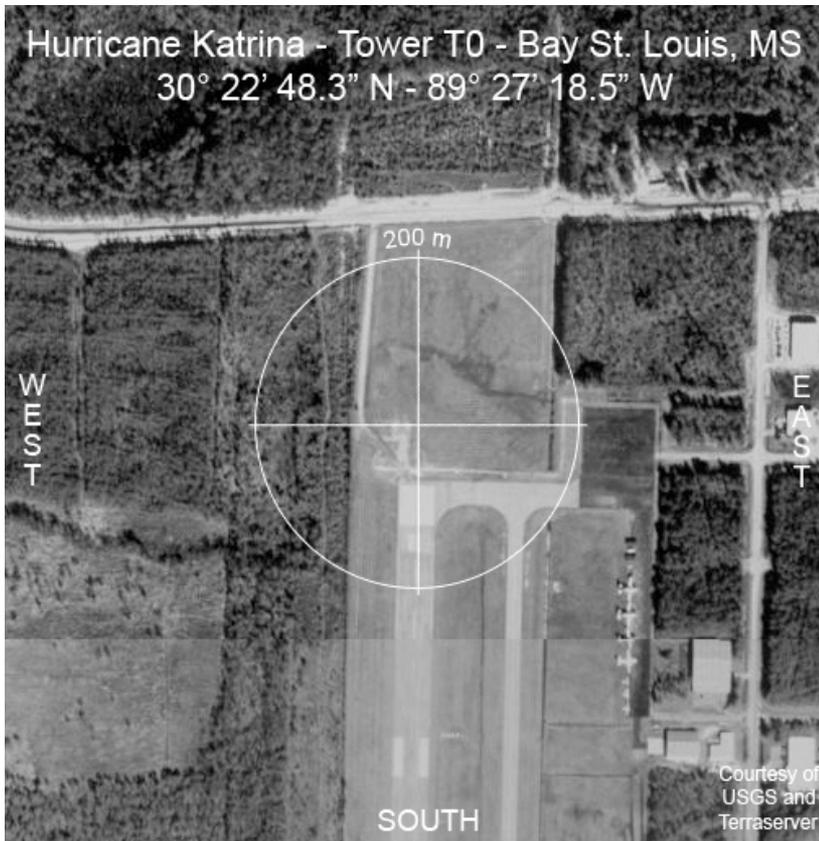
- Have produced estimates of wind speeds for most significant US land falling hurricanes since 2004 for FEMA.
- Estimates from a validated wind field modeling approach
- Katrina and Rita wind speed estimates also published by NIST

ASOS Anemometers Terrain Corrections

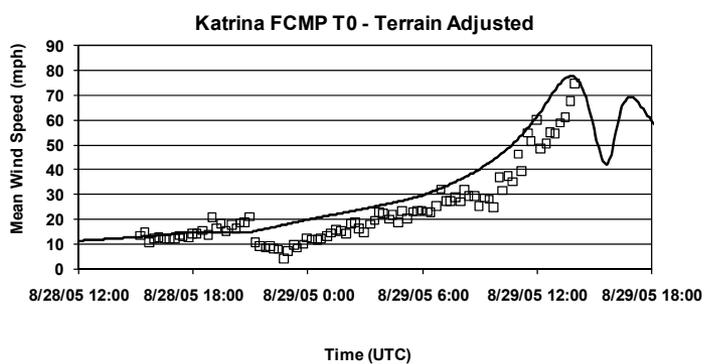
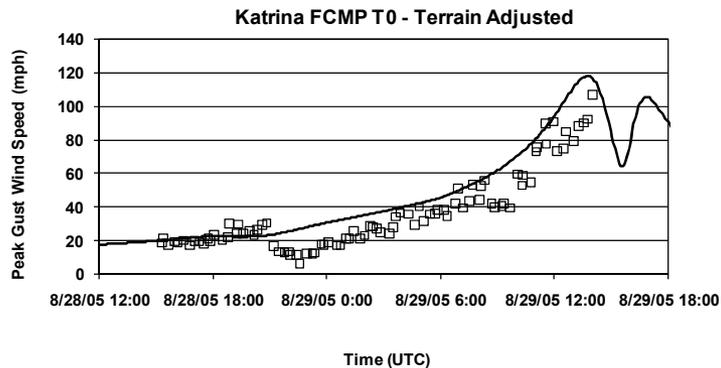
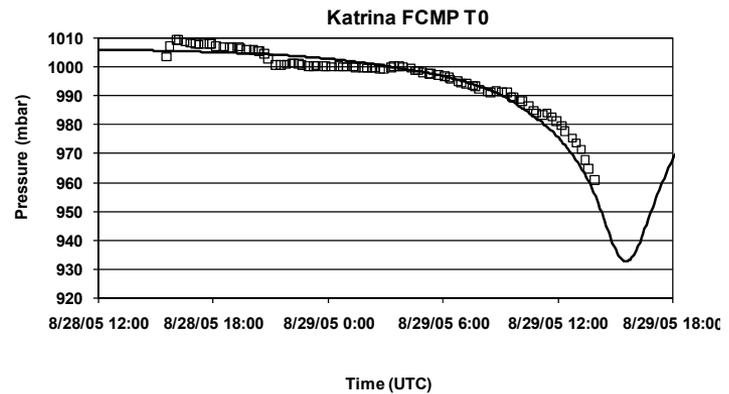
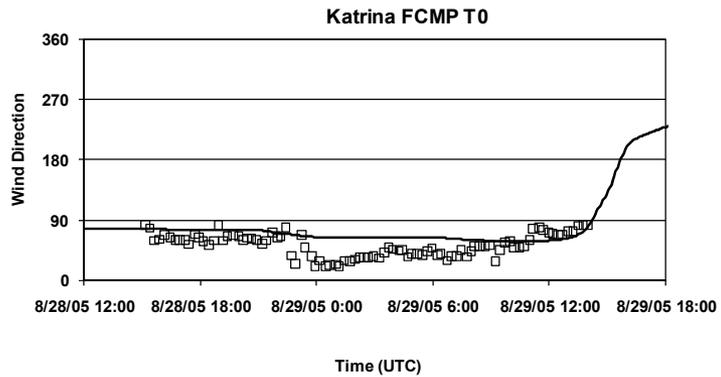
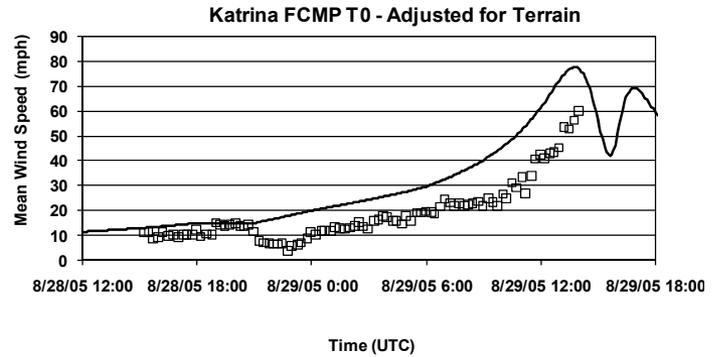
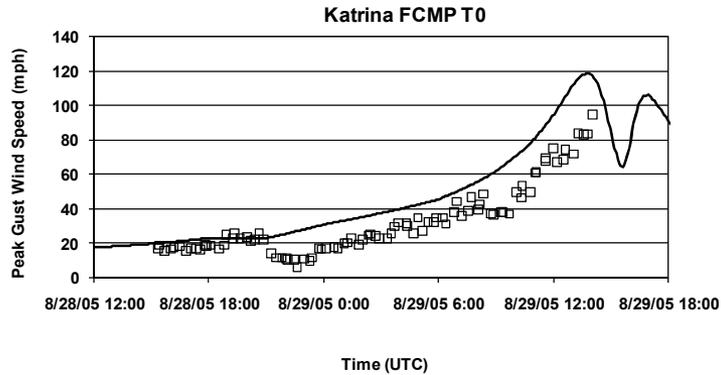


- Open terrain winds for winds from east only
- All other directions wind speed are affected by upstream terrain
- ASOS measurements will generally understate true open terrain wind speeds, unless wind is approaching over a long open fetch.
- Generated direction wind speed correction factors by direction using ESDU

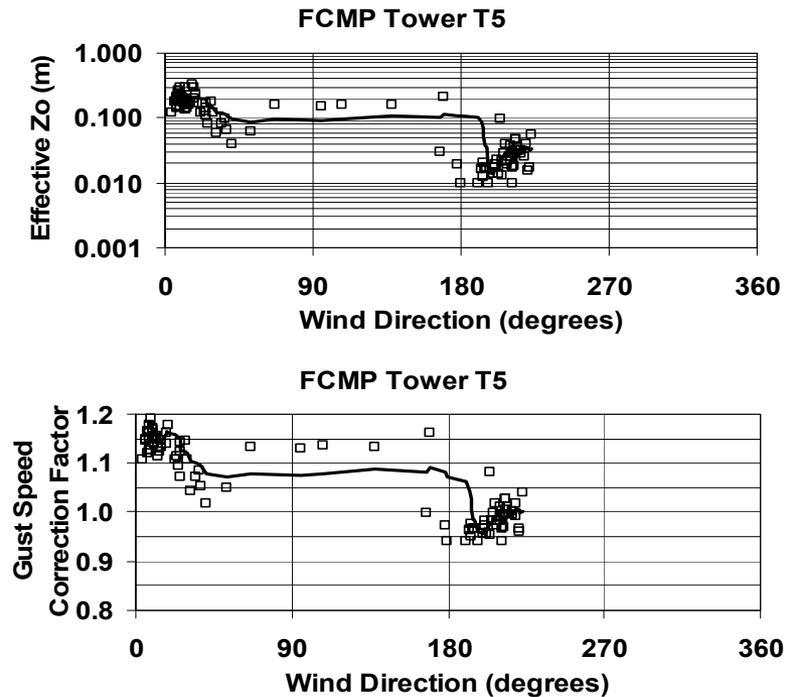
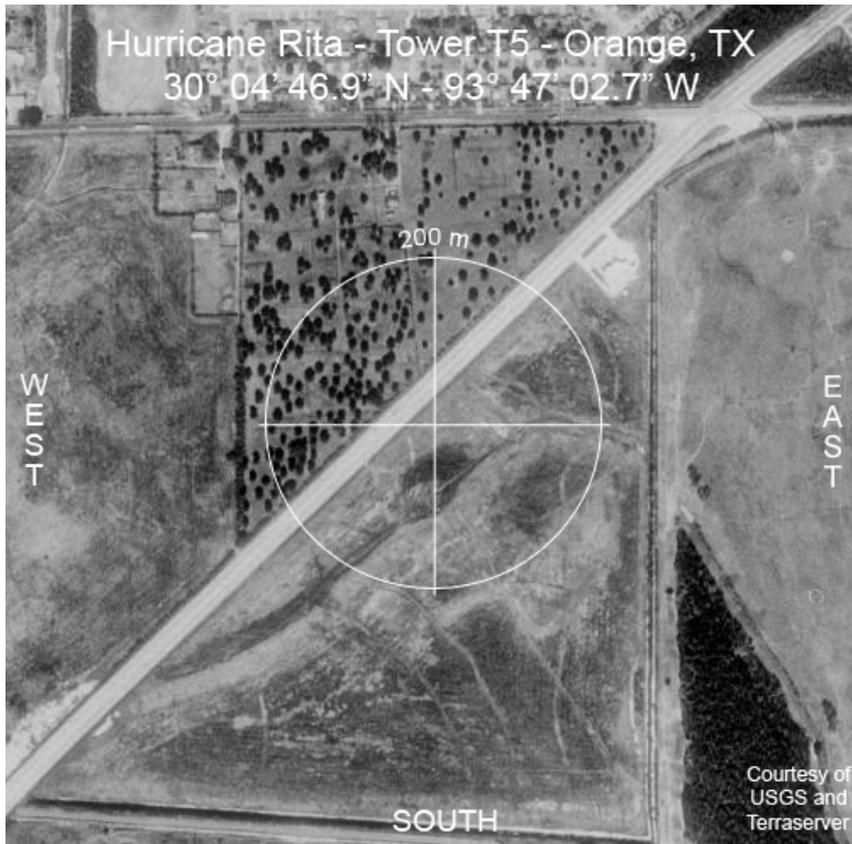
Katrina FCMP T0 – Turbulence Intensity Method



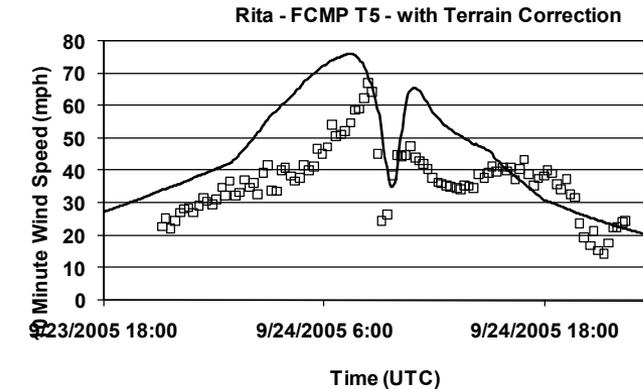
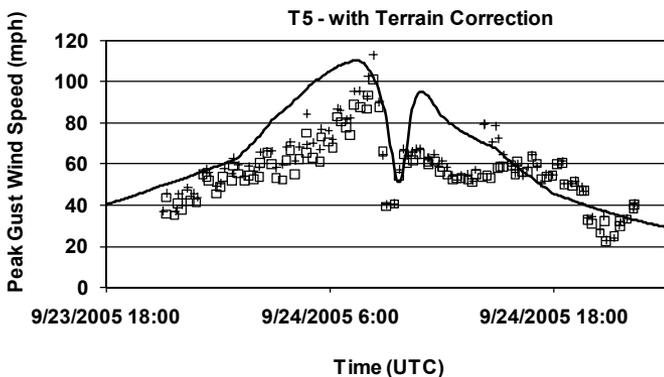
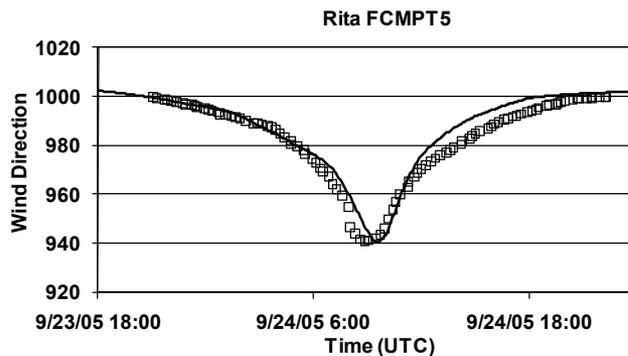
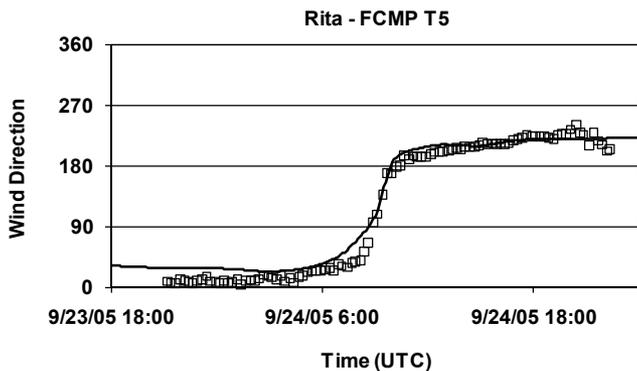
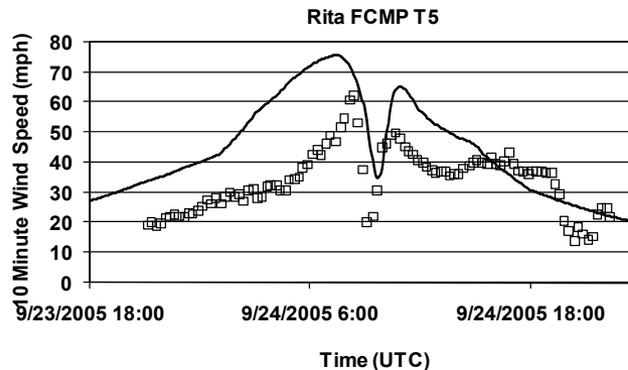
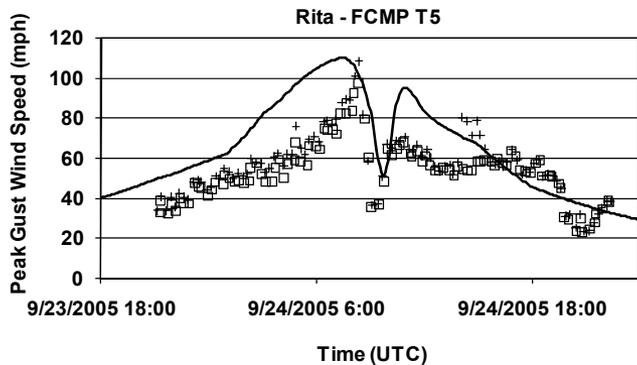
T0 Wind Speed Comparisons



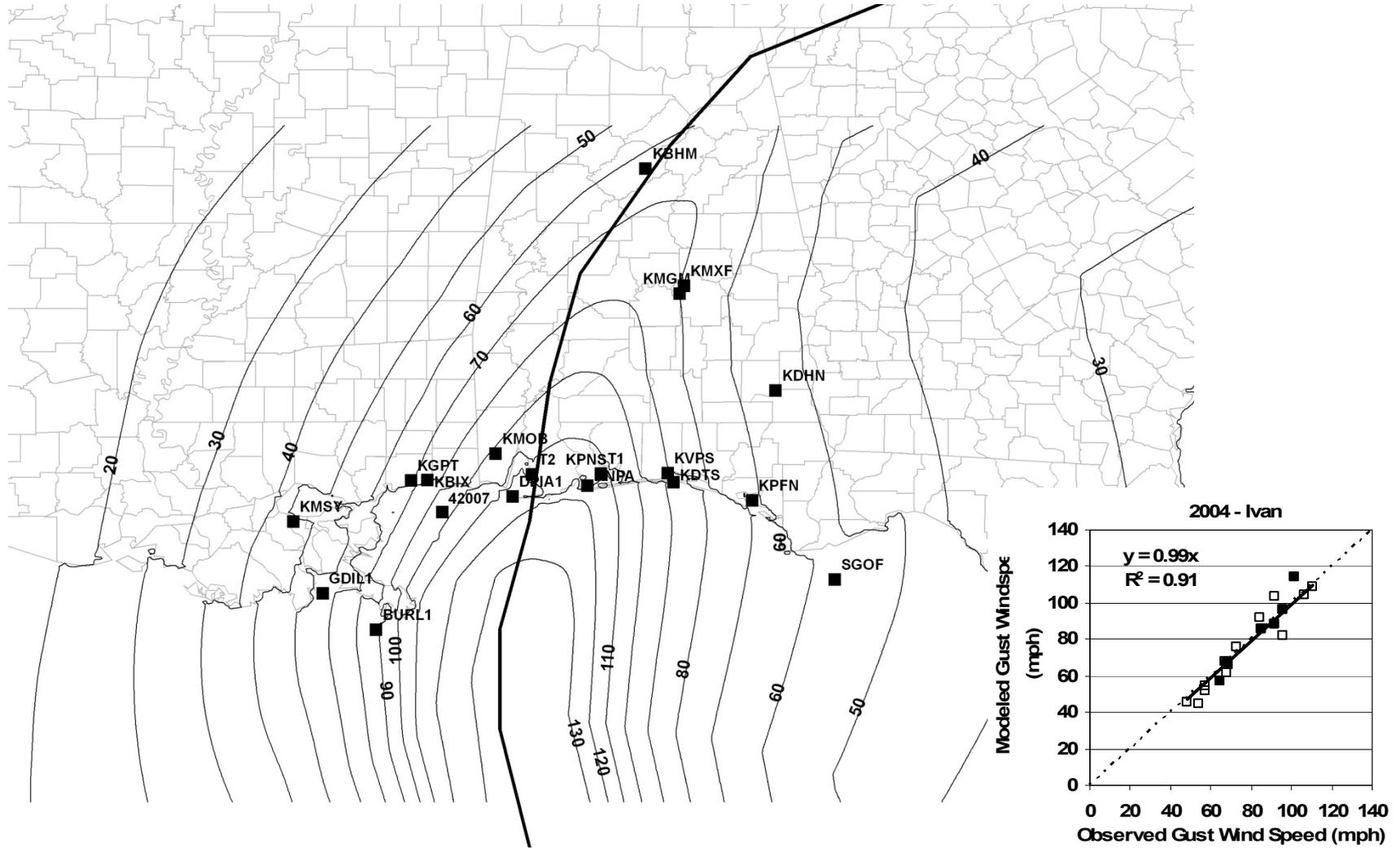
Rita FCMP T5 – Turbulence Intensity Method



T5 Wind Speed Comparisons

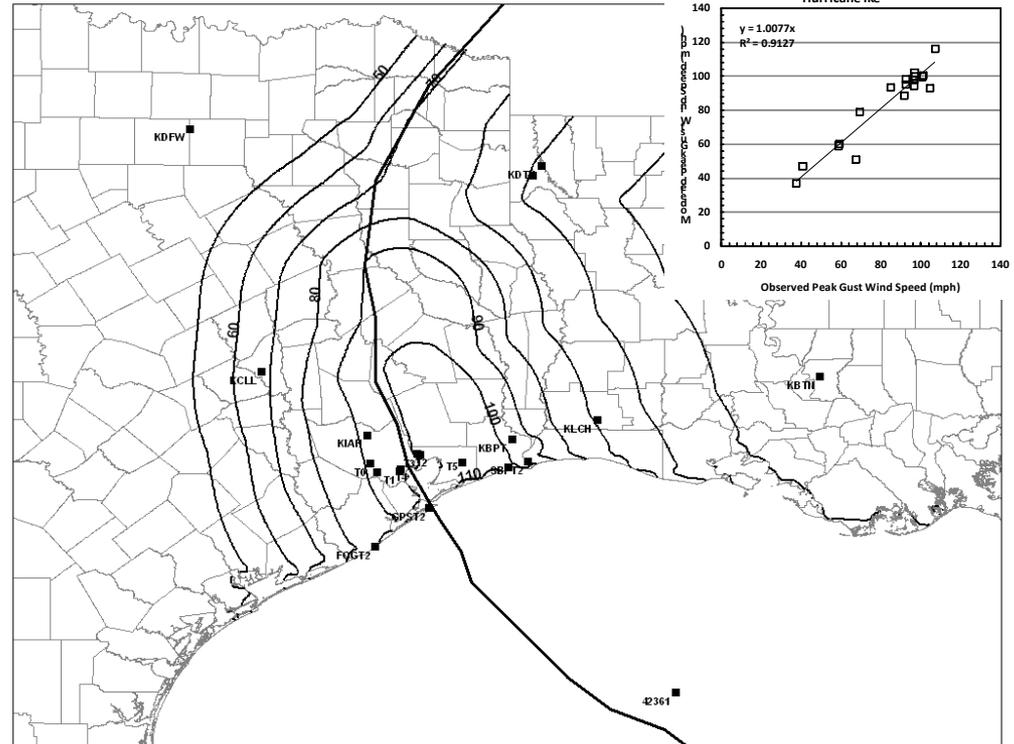
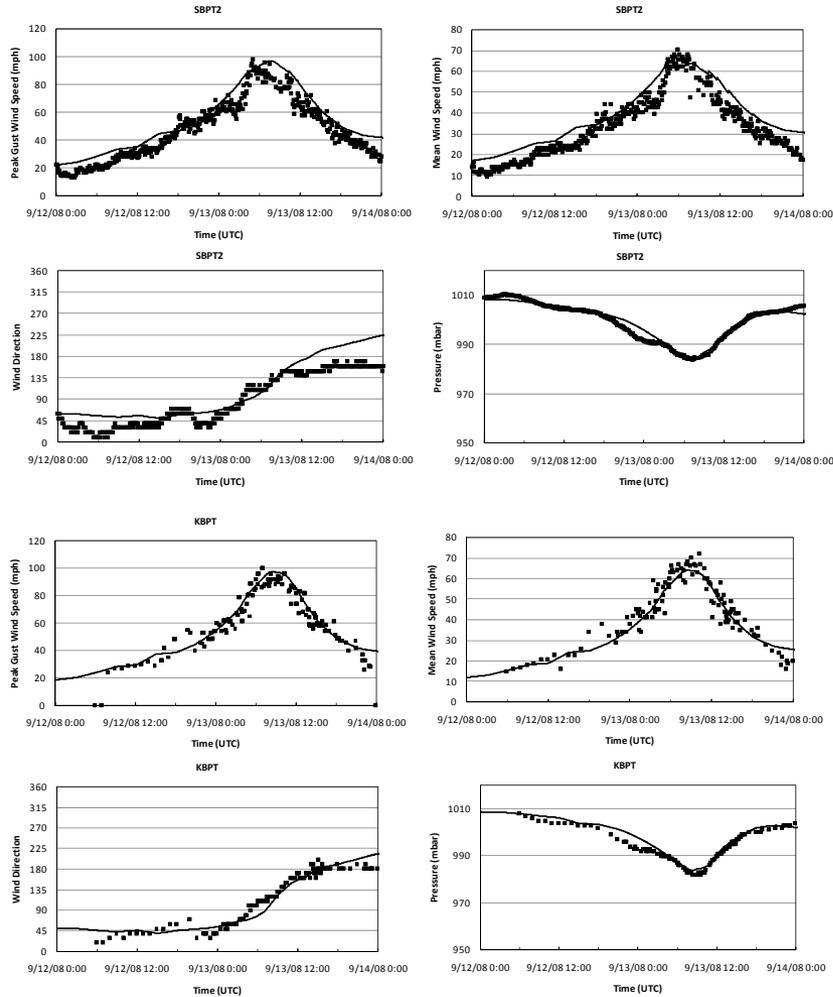


Hurricane Ivan Validation

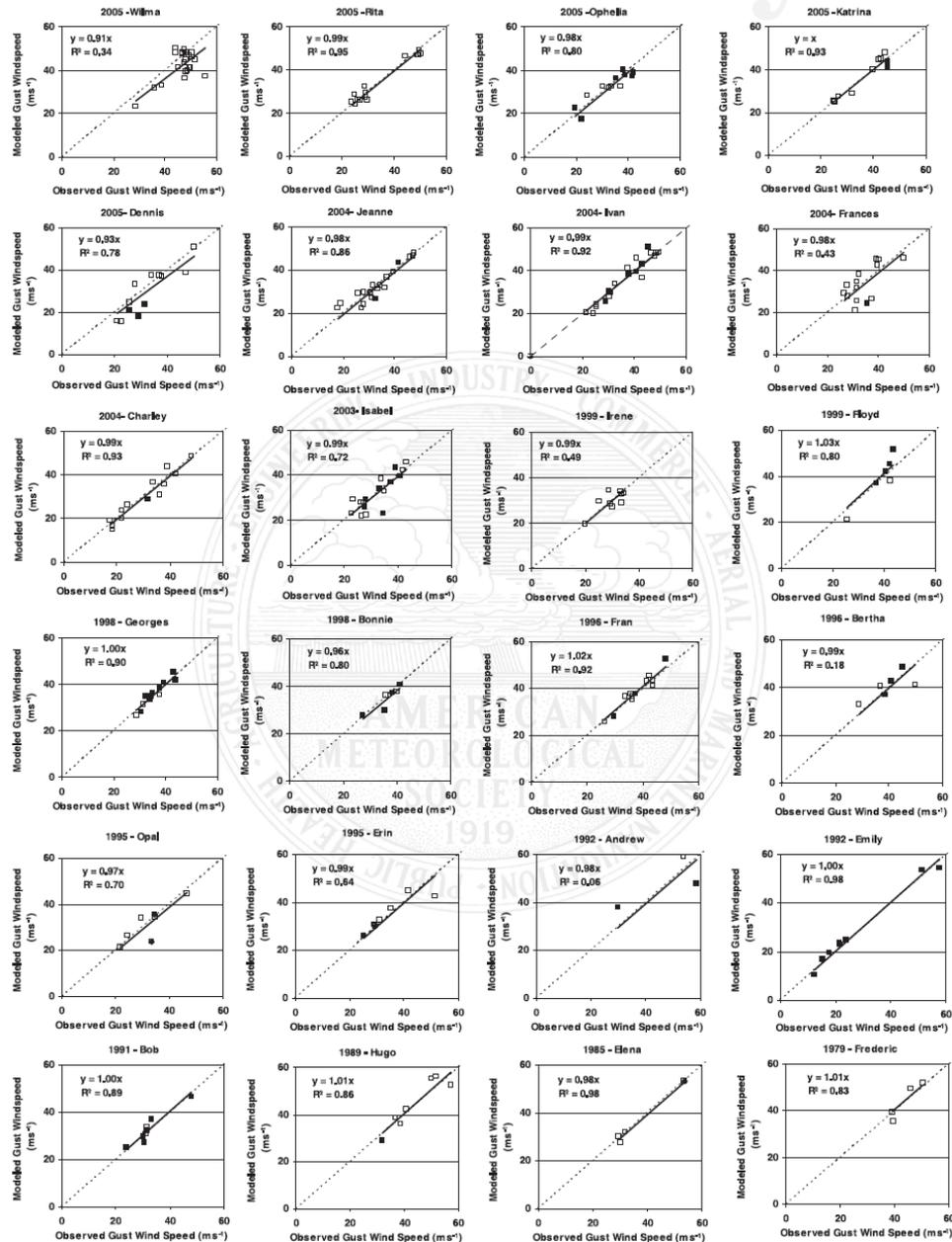


Hurricane Ike

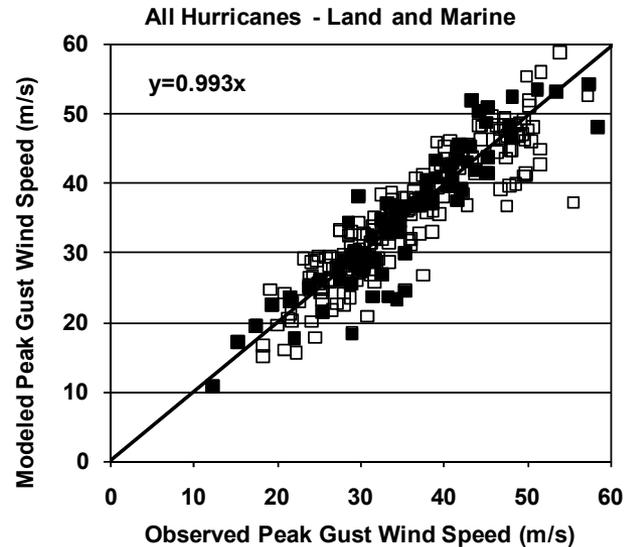
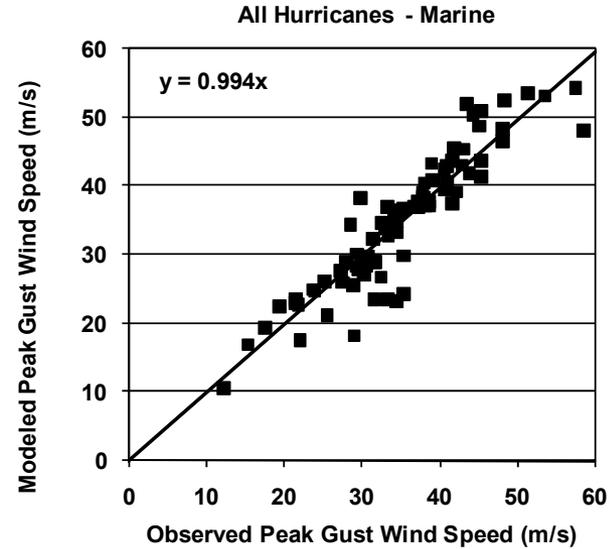
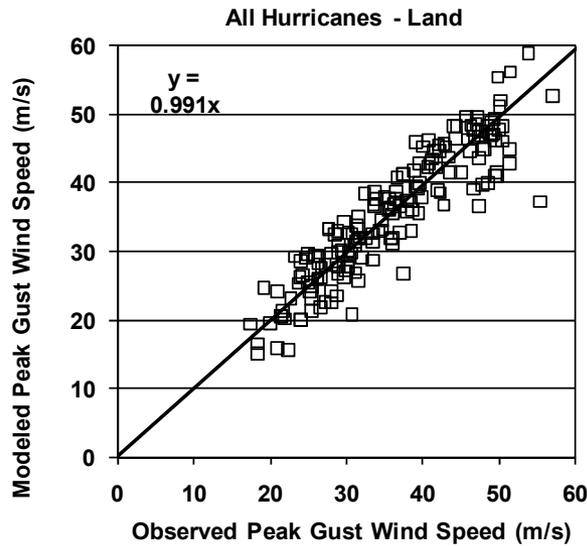
Estimated maximum peak gust wind speed on land
 ~ 110 mph near the coast
 to the right of the landfall location.



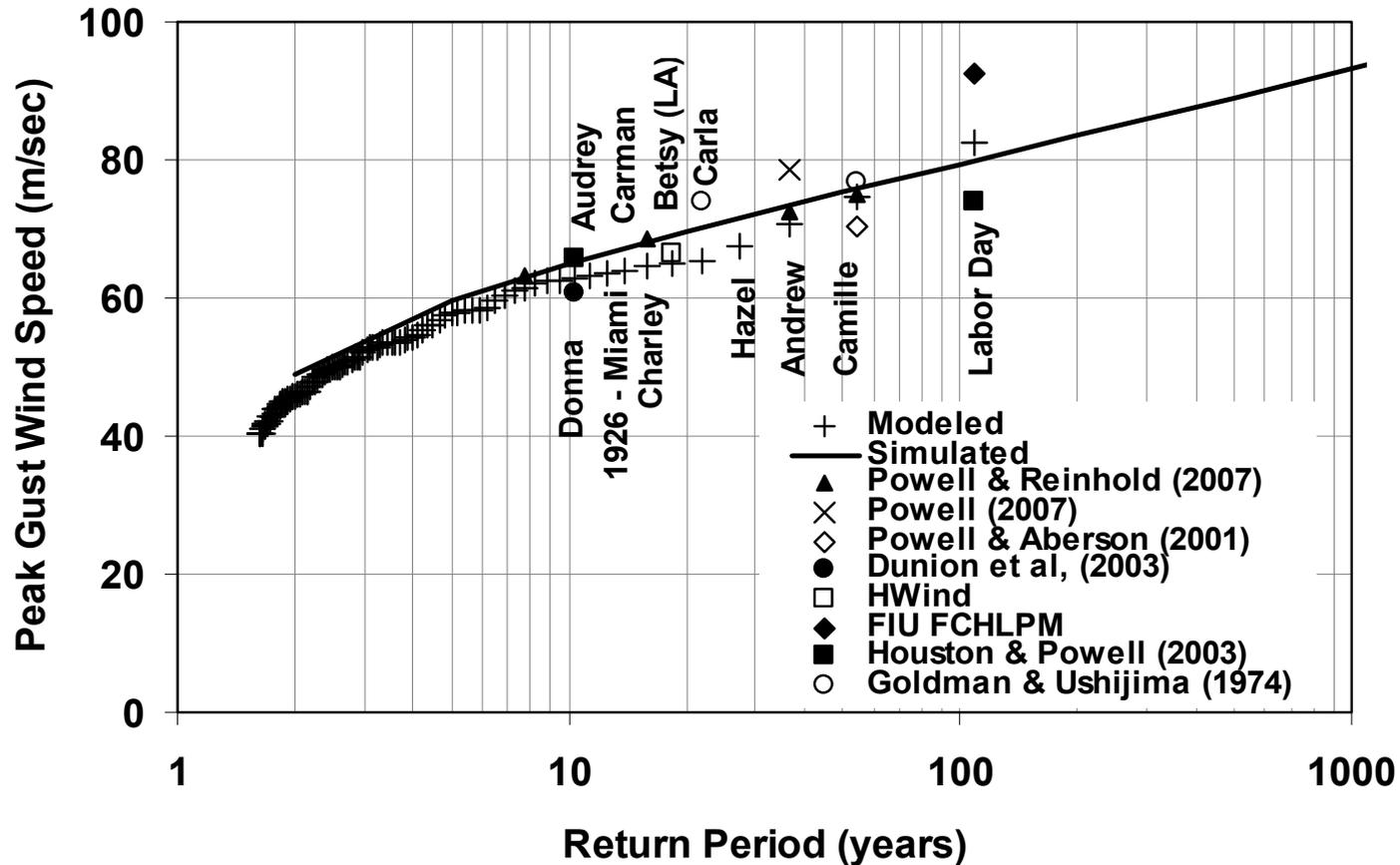
Storm-by-Storm Comparison Summaries



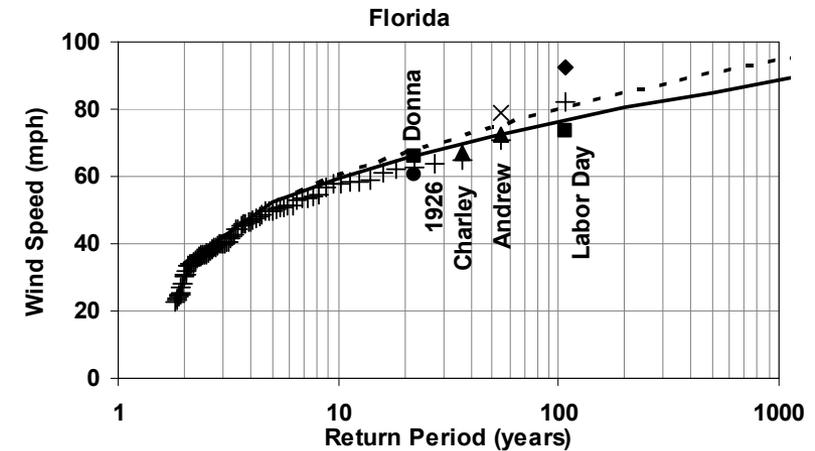
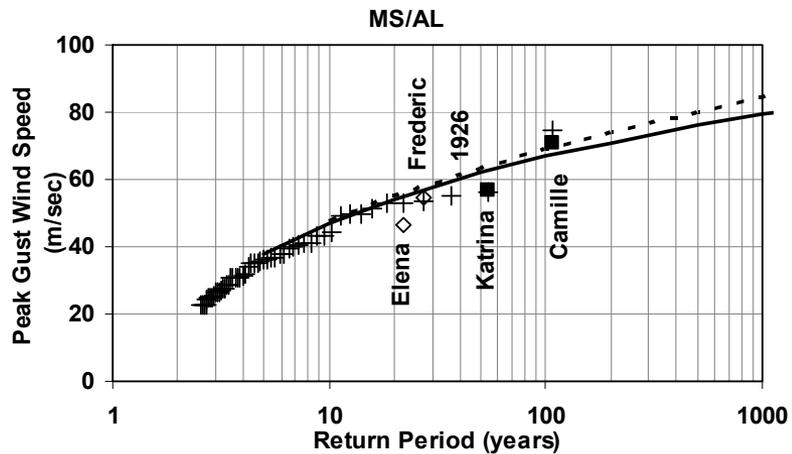
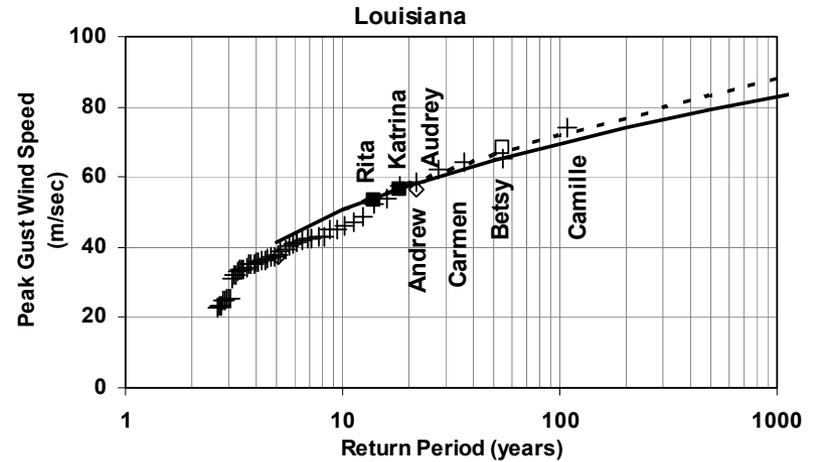
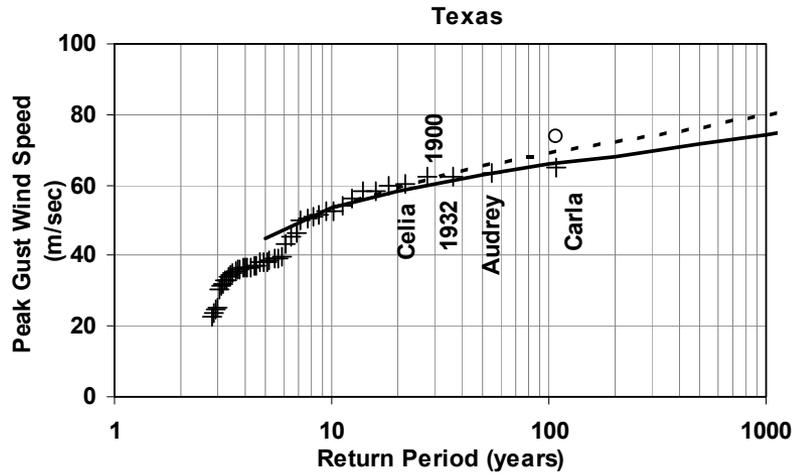
Assessment of Model Errors



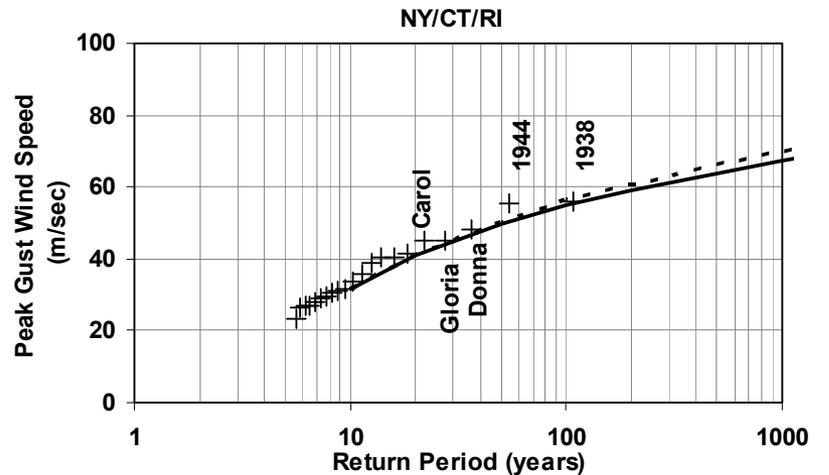
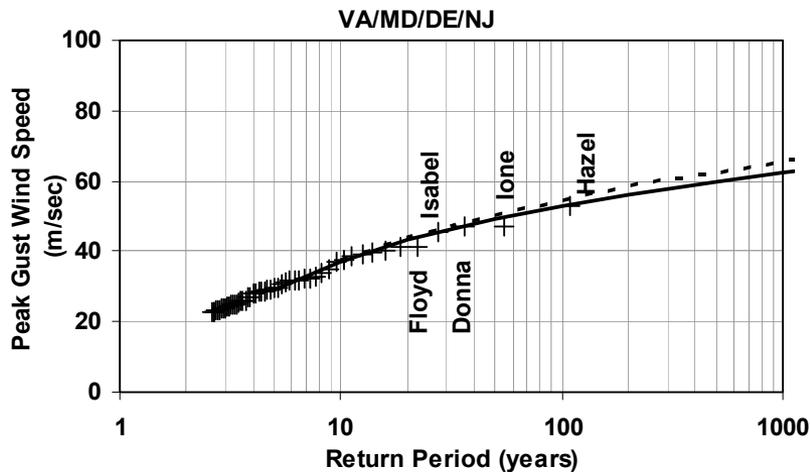
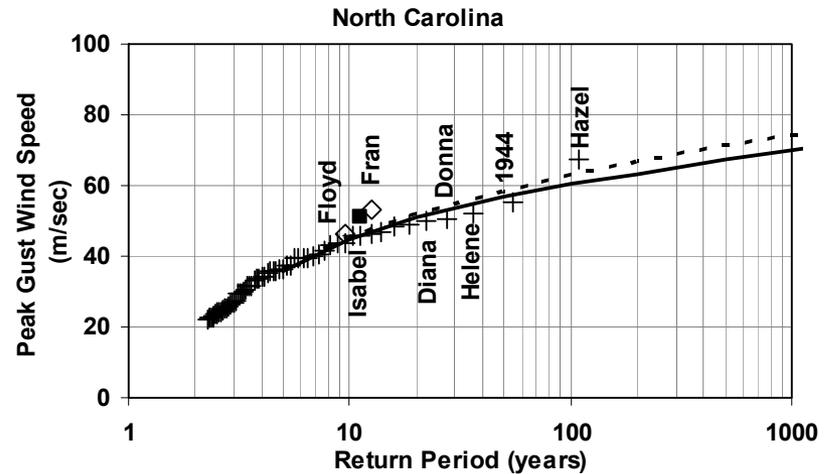
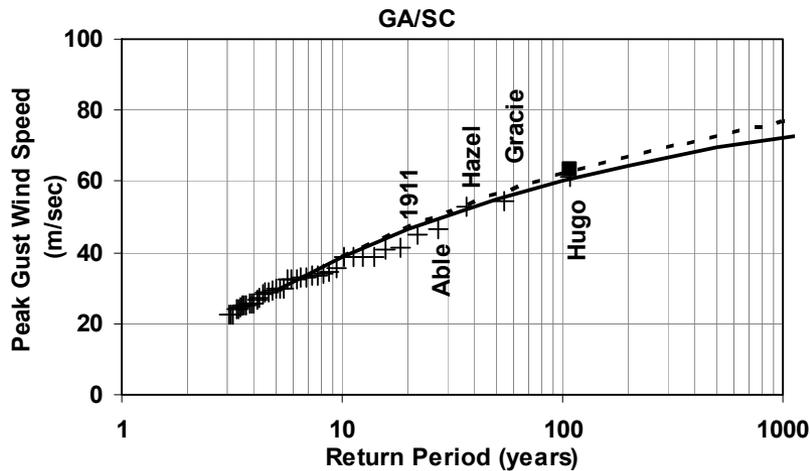
Simulated vs. Historical Maximum Wind Speeds



Simulated vs. Historical Maximum Wind Speeds

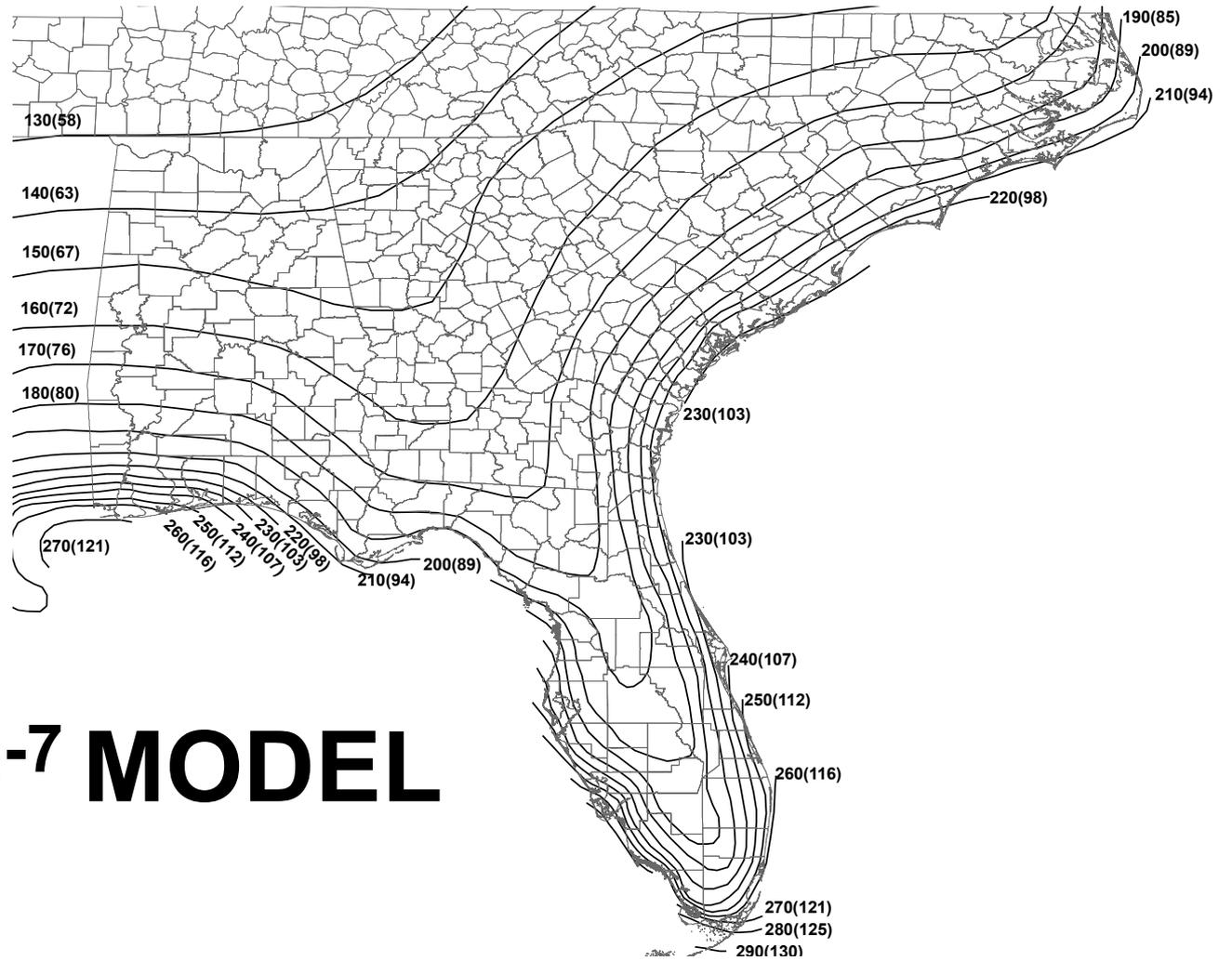


Simulated vs. Historical Maximum Wind Speeds



Original Model Summary

- 2-D Numerical solution of a translating hurricane (slab representation)
- Model change to incorporate smaller minimum values of RMW
- Wind speed variation with height based on dropsonde data
- Extensively validated over both land and water

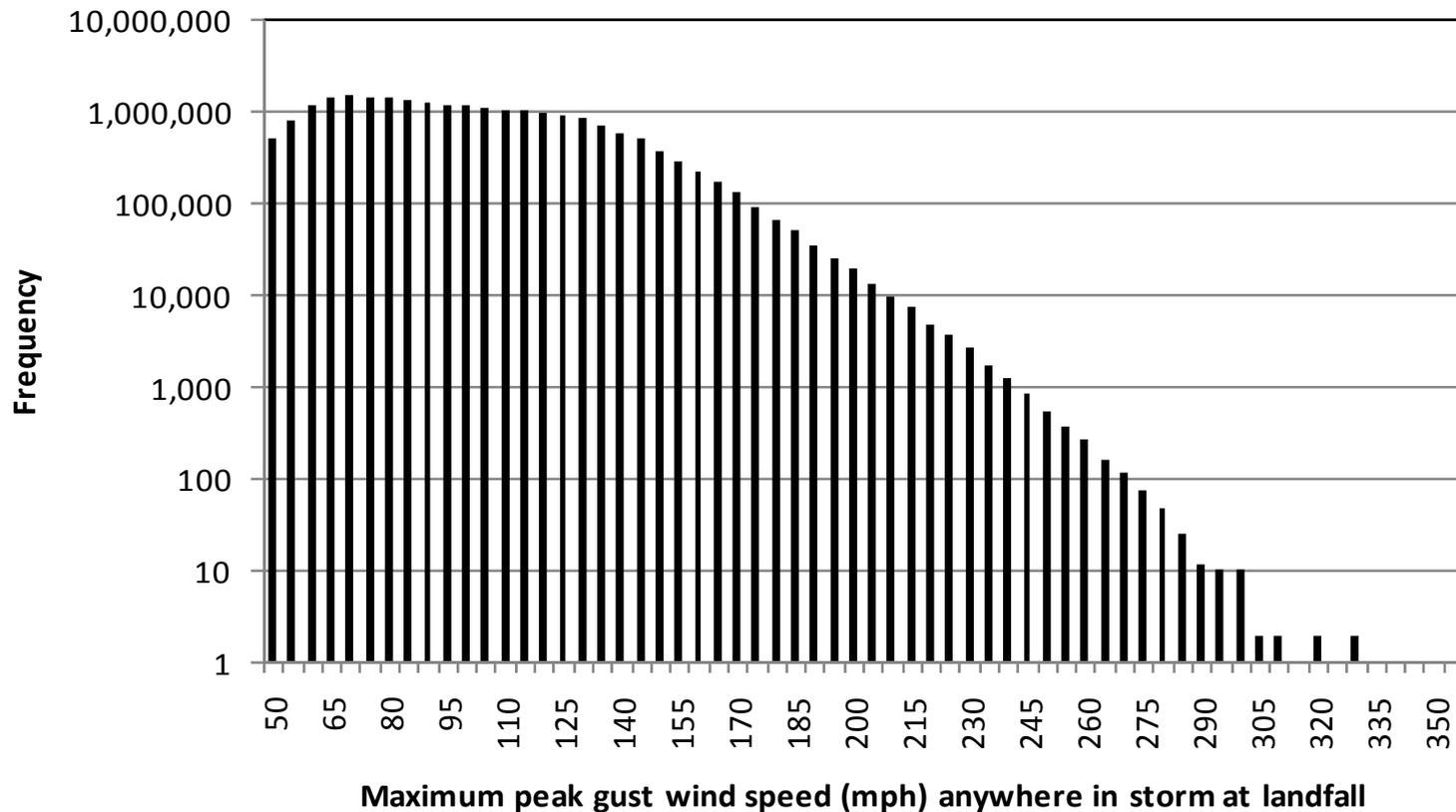


NRC 10^{-7} MODEL

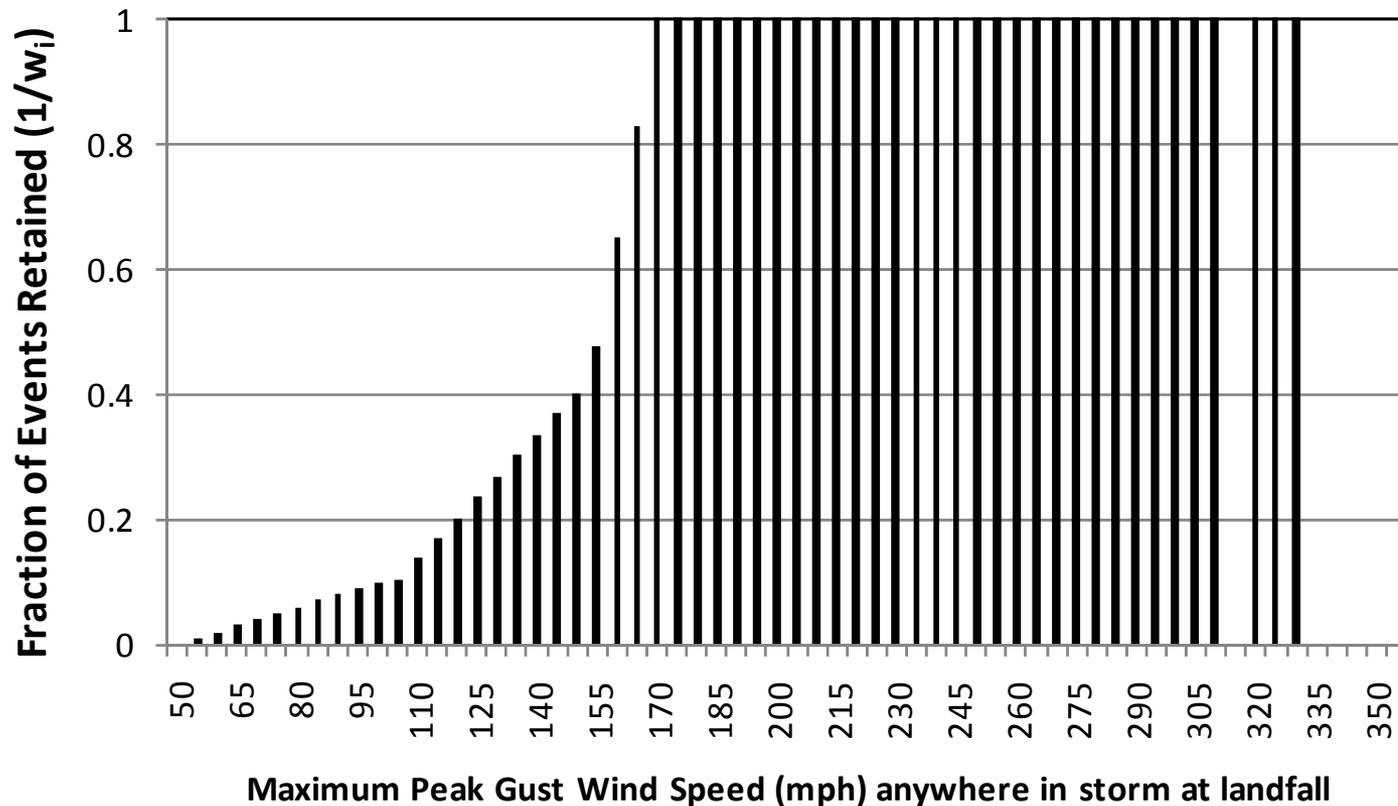
Model Changes

- Smaller minimum RMW (4 km vs. 8 km in original model)
- Reduced storm set for wind speed calculations (23.2 million in full set vs. 3.5 million in reduced set)
- Duration dependent gust factor (lower gust factors for tight, fast storms)

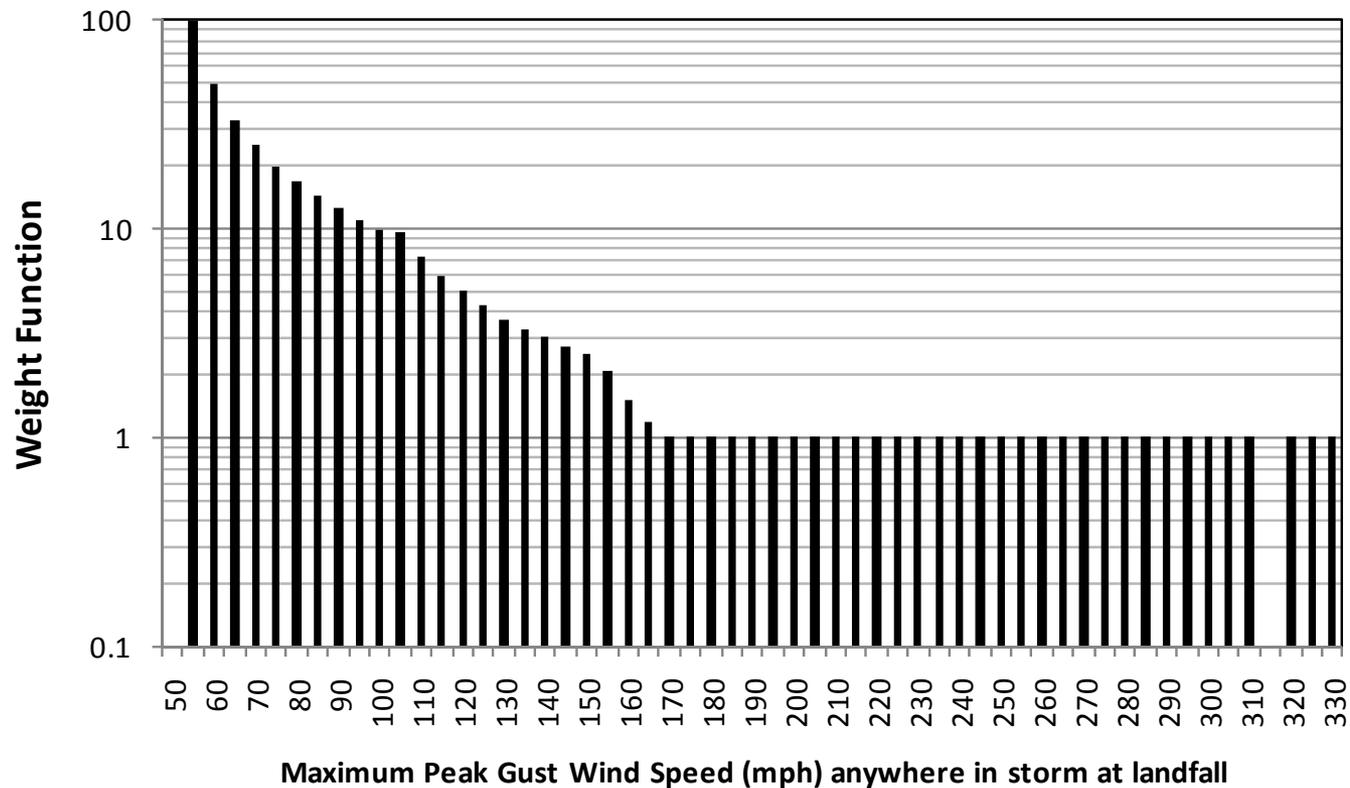
Peak Gust Wind Speed (10m, Marine) at Landfall from 10^7 Year Simulation



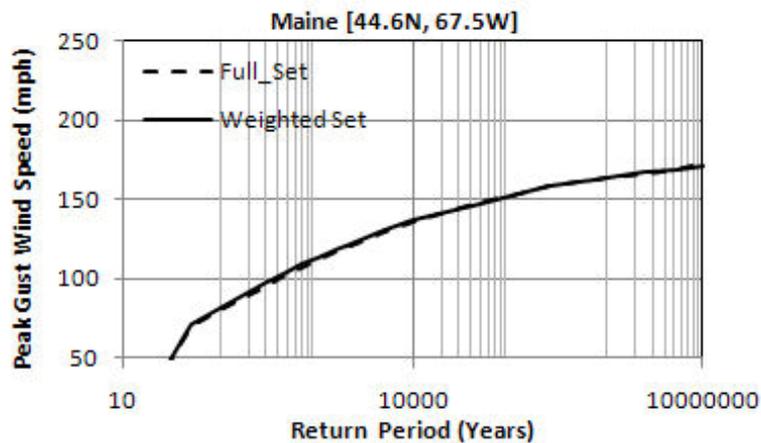
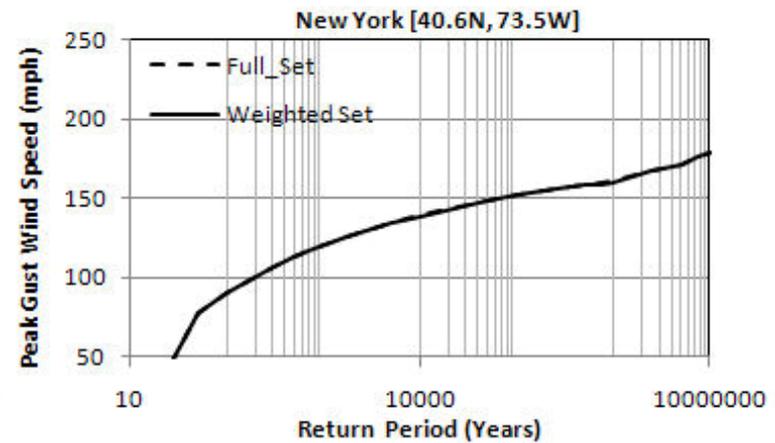
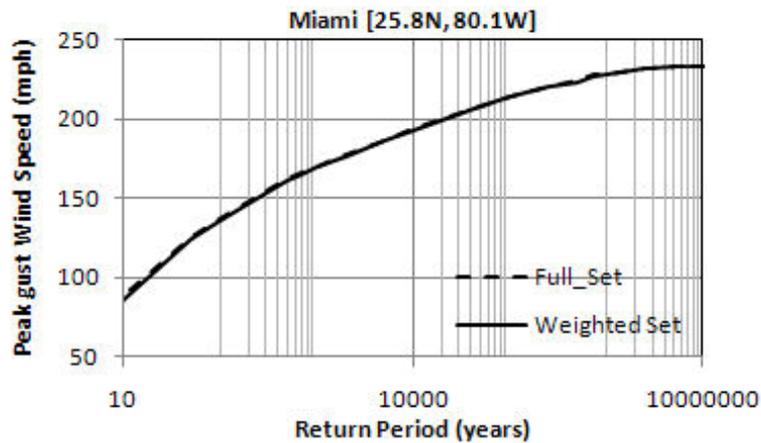
Fraction of Storms Retained vs. Peak Gust Wind Speed (10m, Marine)



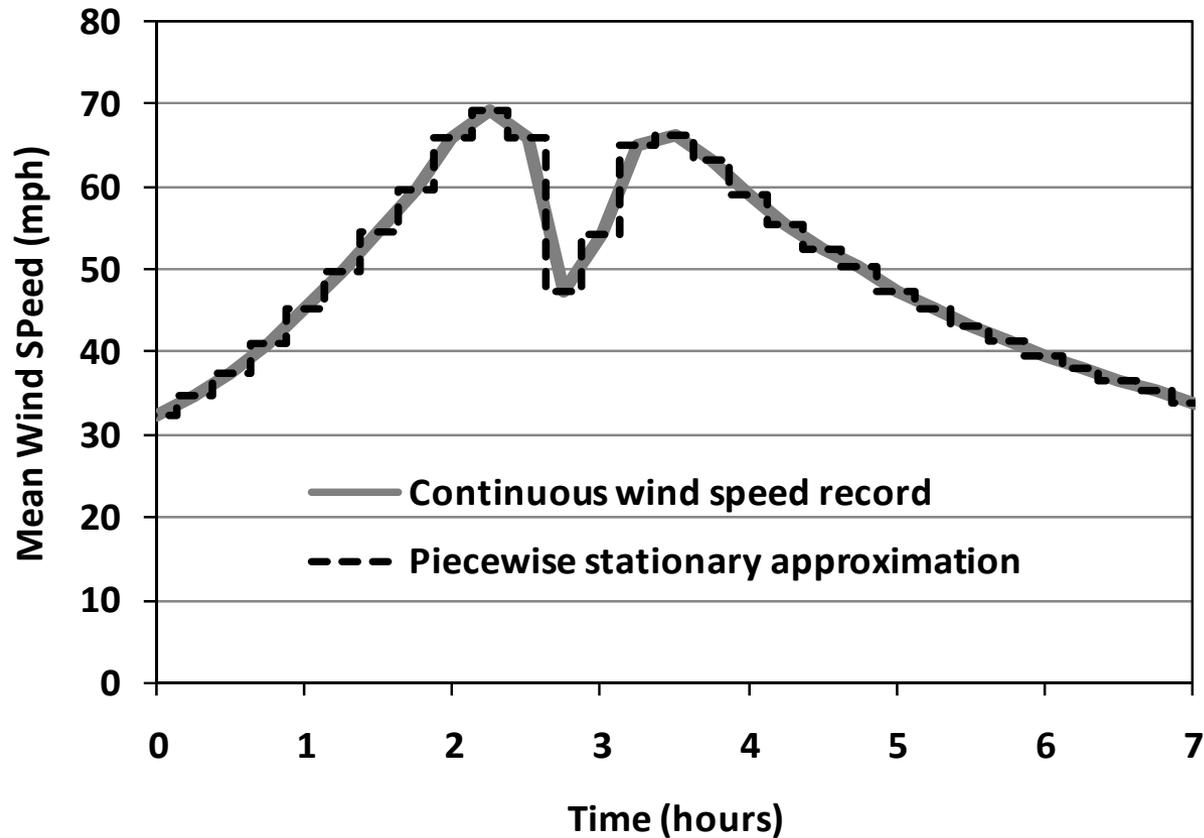
Storm Weight vs. Peak Gust Wind Speed (10m, Marine)



Effect of Reduced Storm Set on Predicted Wind Speeds



Enhanced Gust Factor Consider Storm Duration



Enhanced Gust Factor Considers Storm Duration

- Following Davenport (1964), a non-dimensional variable η is defined as: $\eta = \frac{u - \bar{u}}{\sigma(u)}$
- the cumulative density function for the largest maxima within a segment is:

$$P_{\max_i}(\eta) = \exp\left[-vT \exp\left(-\frac{\eta^2}{2}\right)\right]$$

- $P_{\max}(u)$ within a segment is $P_{\max_i}(u) = \exp\left[-vT \exp\left(-\frac{1}{2}\left(\frac{u - \bar{u}}{\sigma(u)}\right)^2\right)\right]$

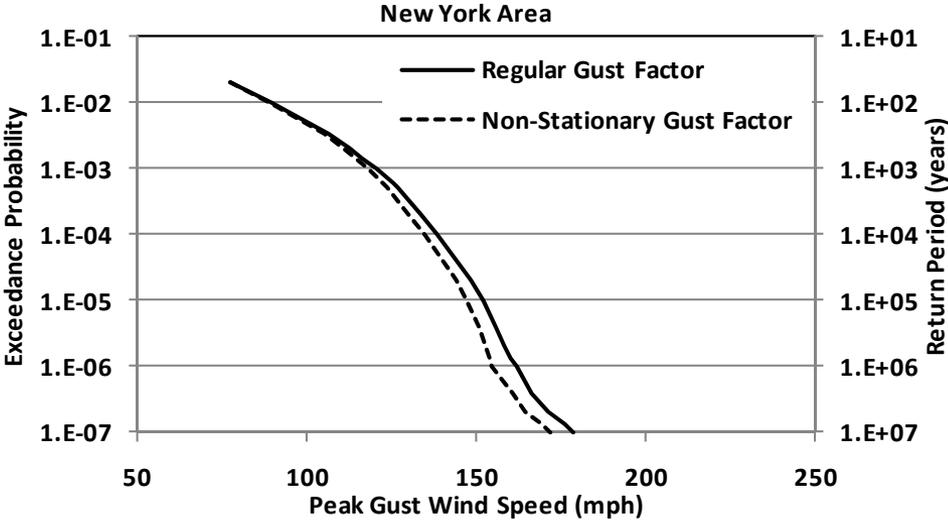
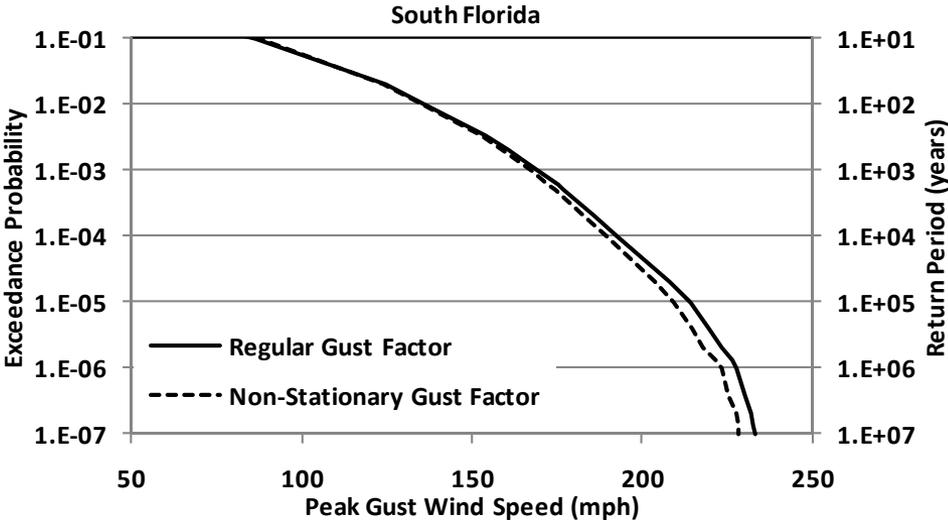
- For multiple segments $P_{\max}(u) = \prod_{i=1}^N P_{\max_i}(u)$

- Mean peak-gust wind speed \hat{u} is $\hat{u} = \int_0^{\infty} u p_{\max}(u) du$; $\hat{u} = u + g\sigma(u)$

- The peak factor g is $g = \sqrt{2 \ln vT} + \frac{0.577}{\sqrt{2 \ln vT}} + \dots$

- Crossing rate v is computed using the ESDU (1982) models for atmospheric turbulence

Enhanced Gust Factor Considers Storm Duration



Translation speed adjustment

- To reduce the overestimation of the translation speed effect on rapidly moving hurricanes, we implemented a reduced translation speed so that the effective translation speed c_{eff} passed into the wind field model is defined by:

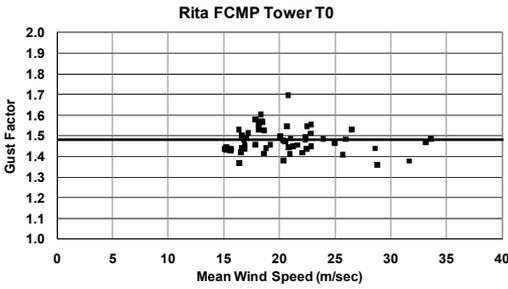
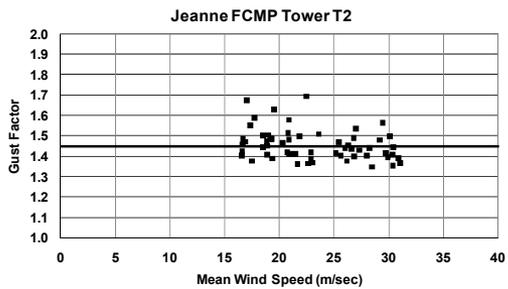
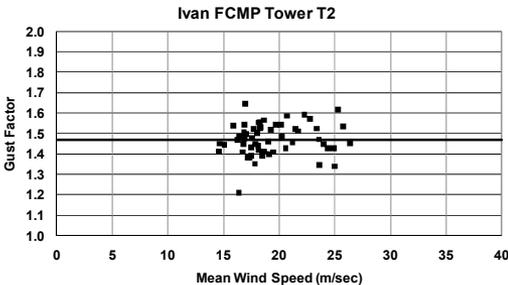
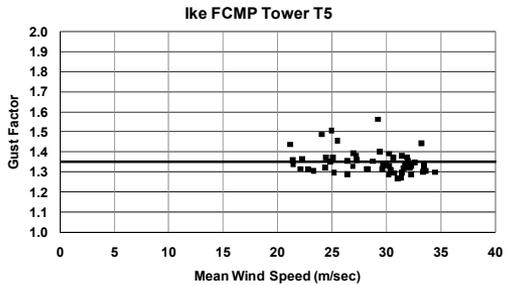
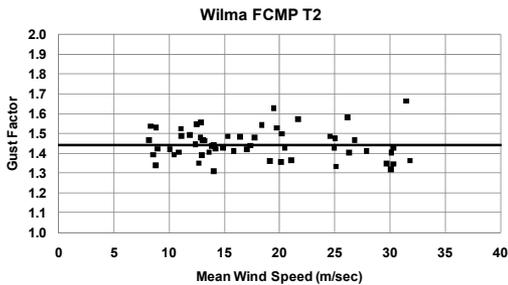
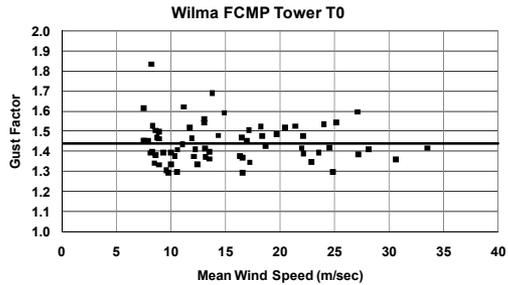
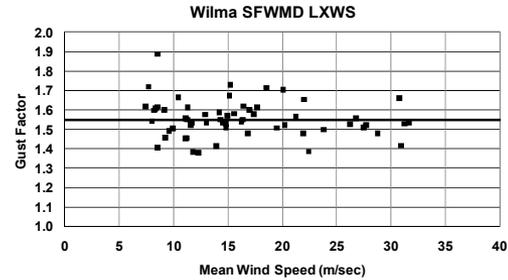
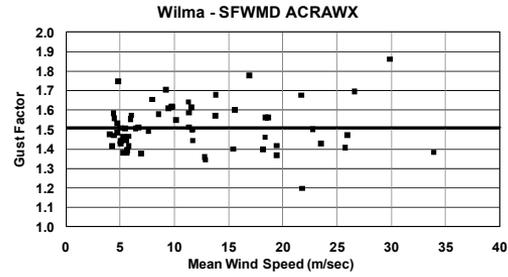
$$c_{\text{eff}} = c, \quad c < 15 \text{ m/s}$$

$$c_{\text{eff}} = 15 + \frac{c - 15}{3}, \quad 15 < c < 30 \text{ m/s}$$

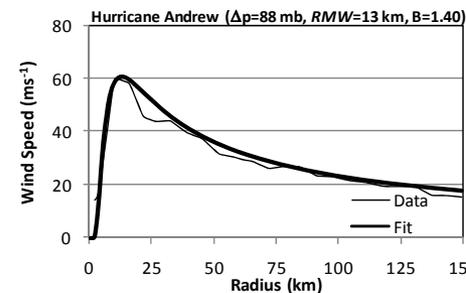
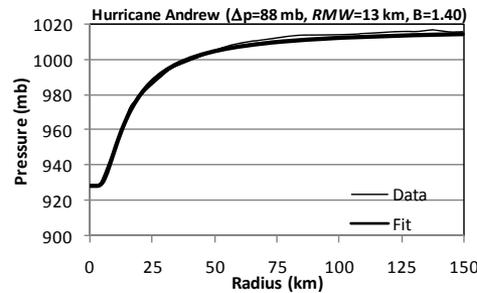
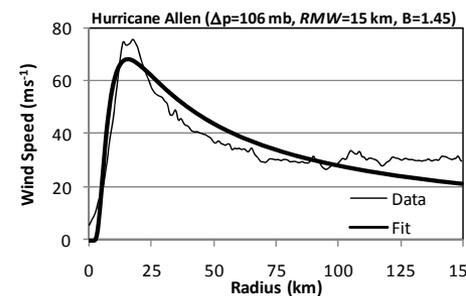
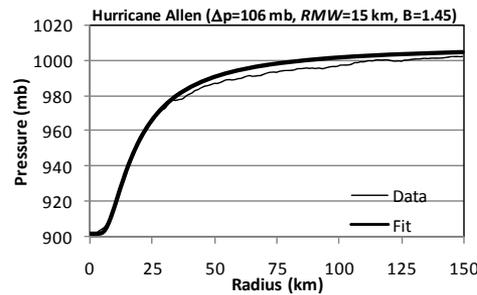
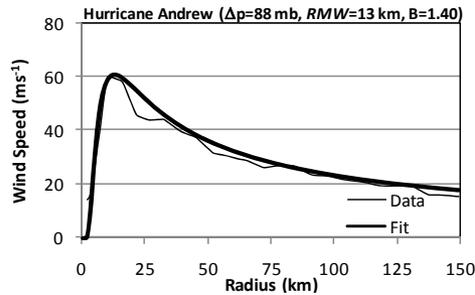
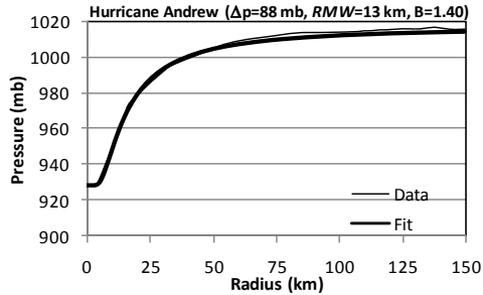
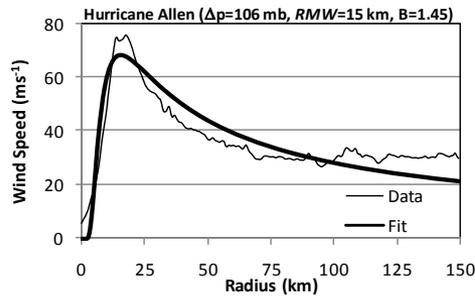
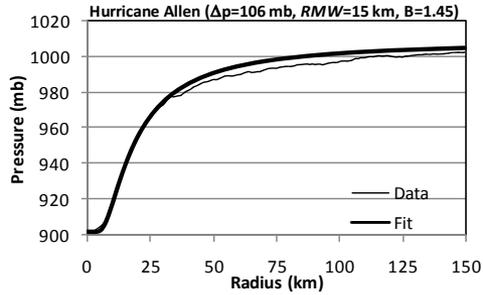
$$c_{\text{eff}} = 20, \quad c > 30 \text{ m/s}$$

- where c is the original translation speed
- This modified translation speed improved comparisons between model and observed winds for the 1938 hurricane and has since been used in Hurricane Juan validations (Halifax, MS)

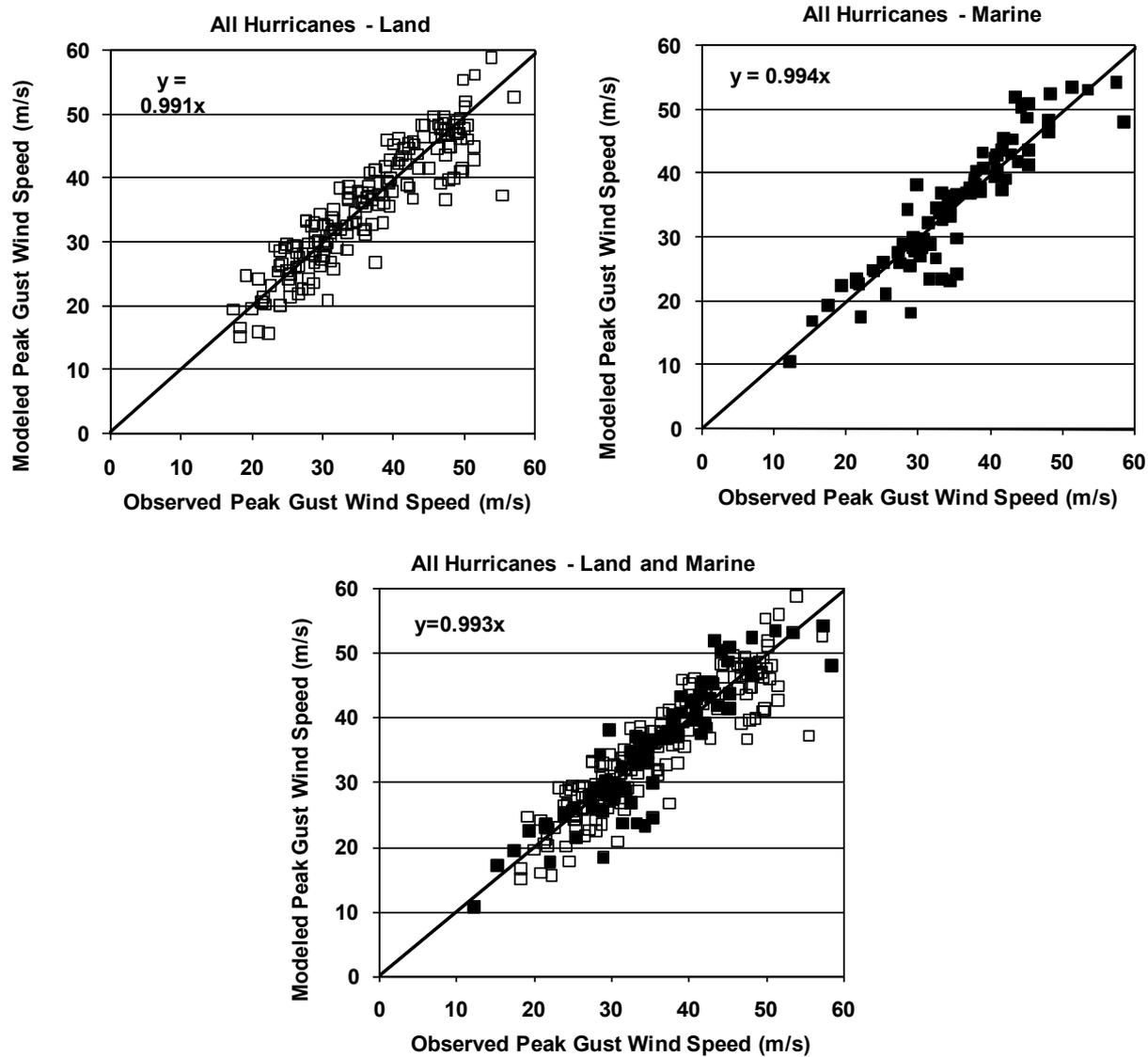
Windfield Modeling Uncertainties: Example Gust Factor Errors



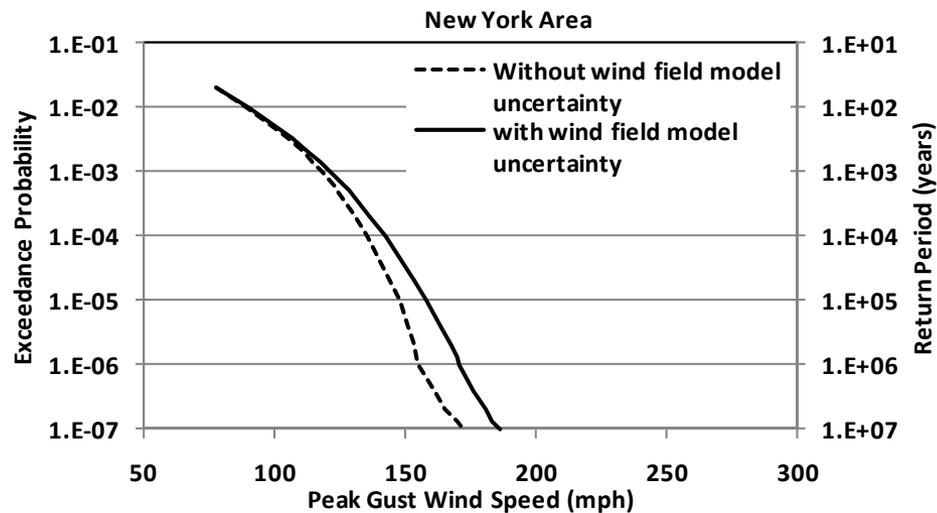
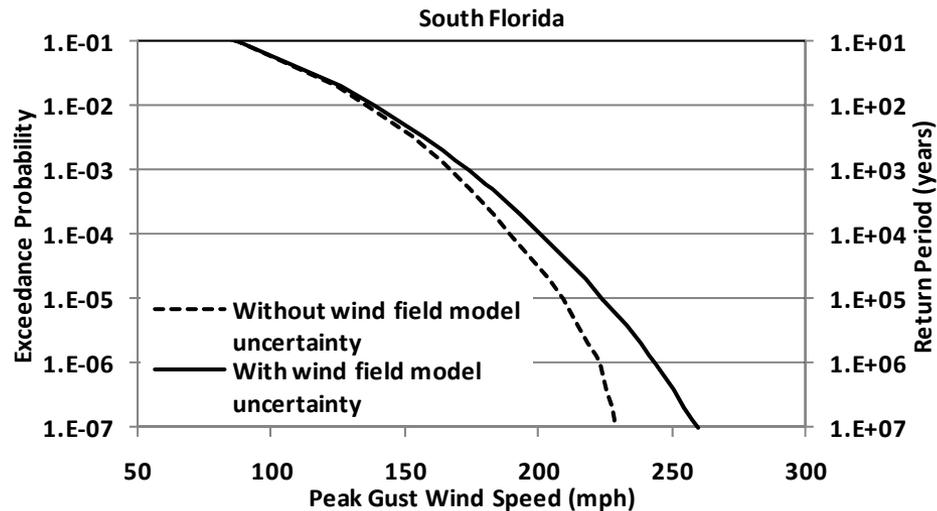
Windfield Modeling Uncertainties: Example Wind Model Limitations



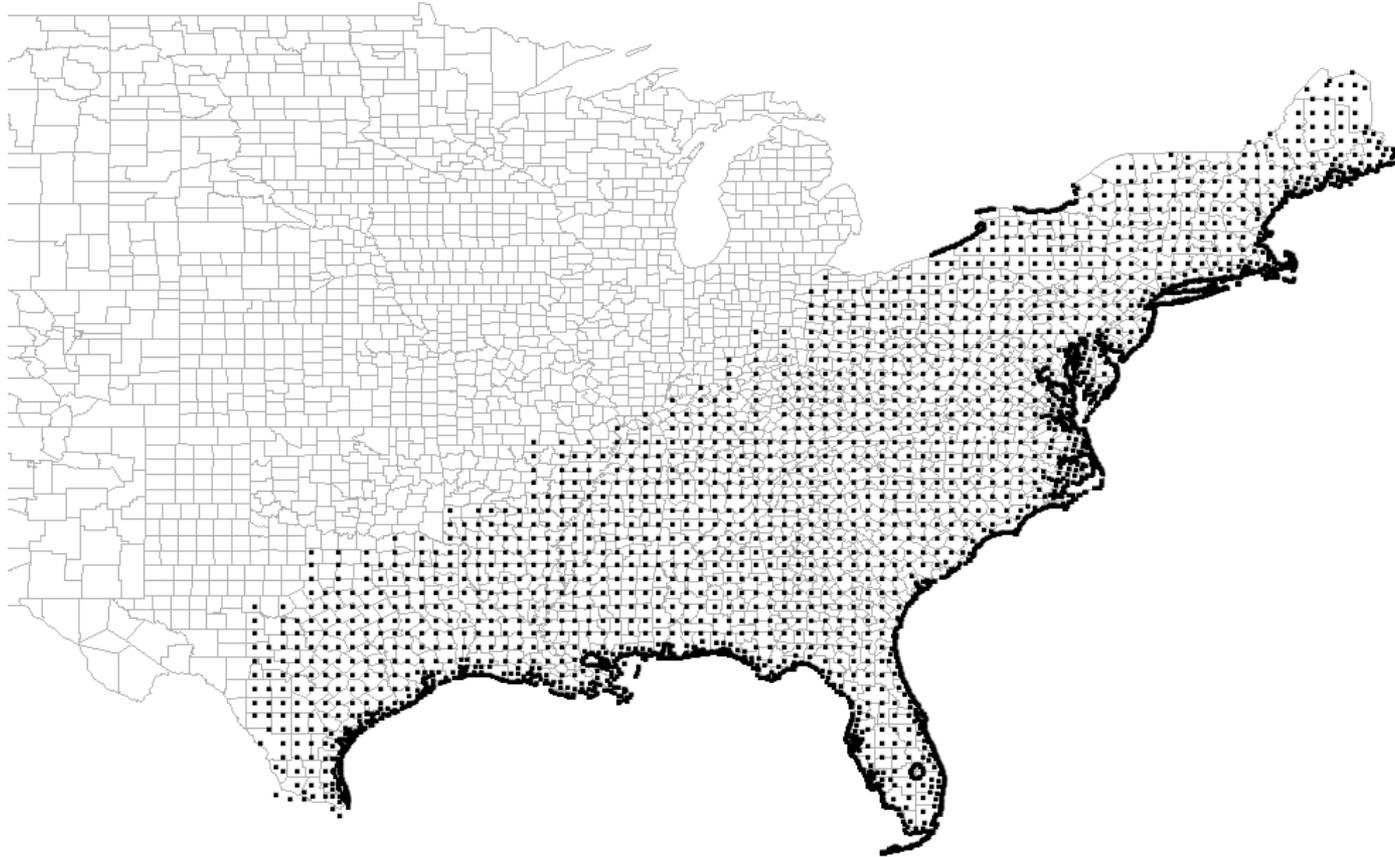
Windfield Model Uncertainty



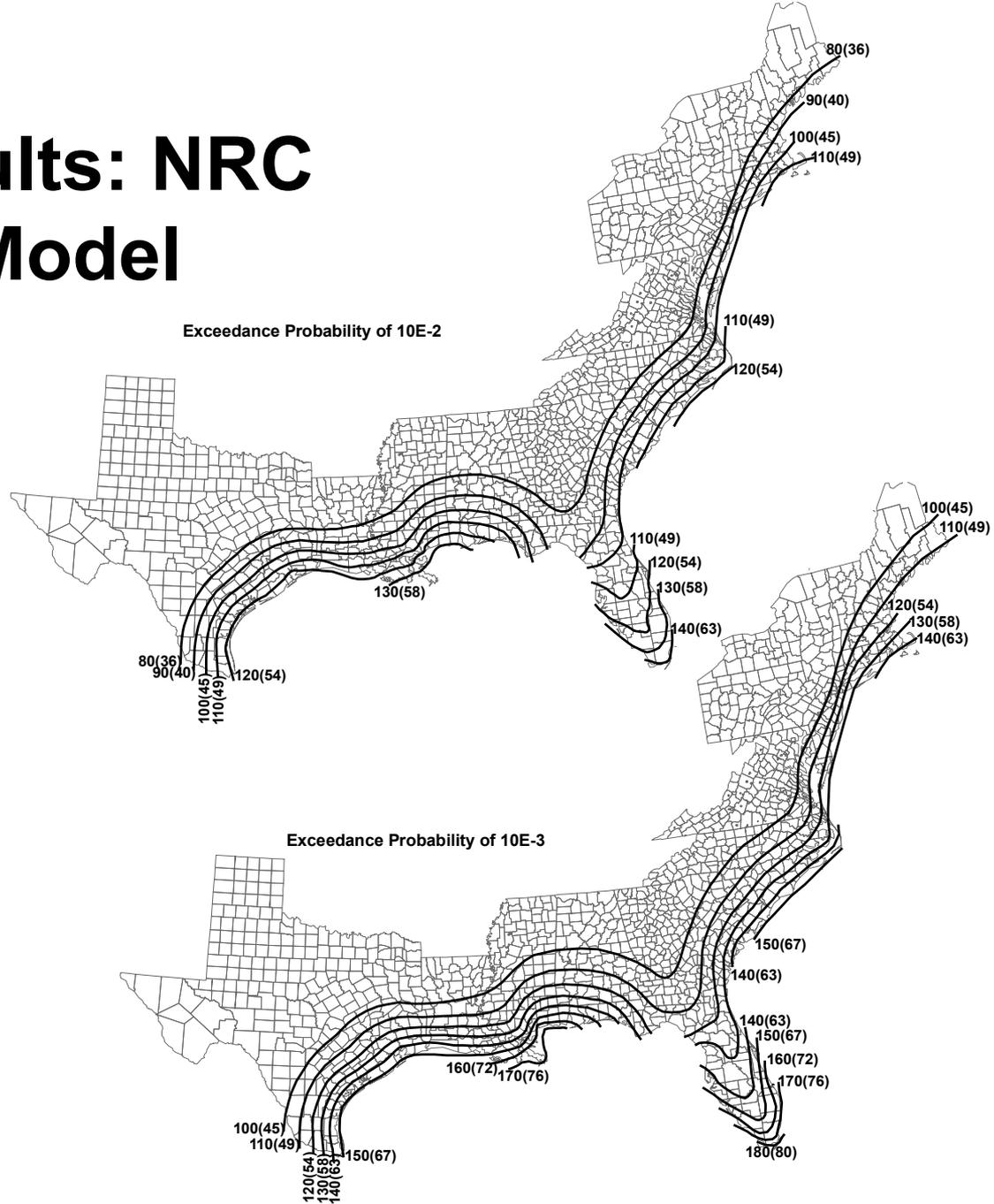
Windfield Modeling Uncertainties: Example Impacts on Wind Speeds



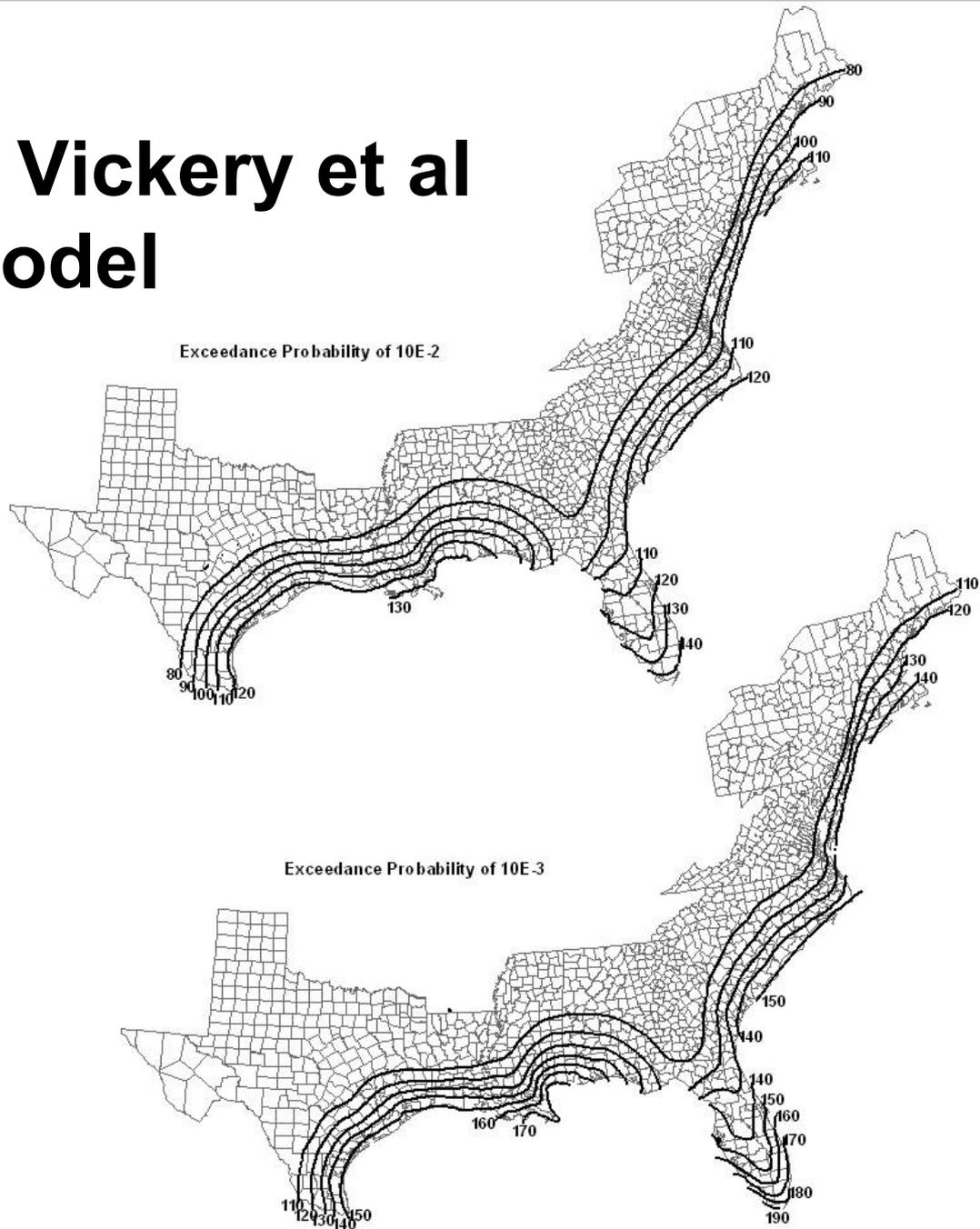
Locations of 3575 Points for Wind Speed Computations



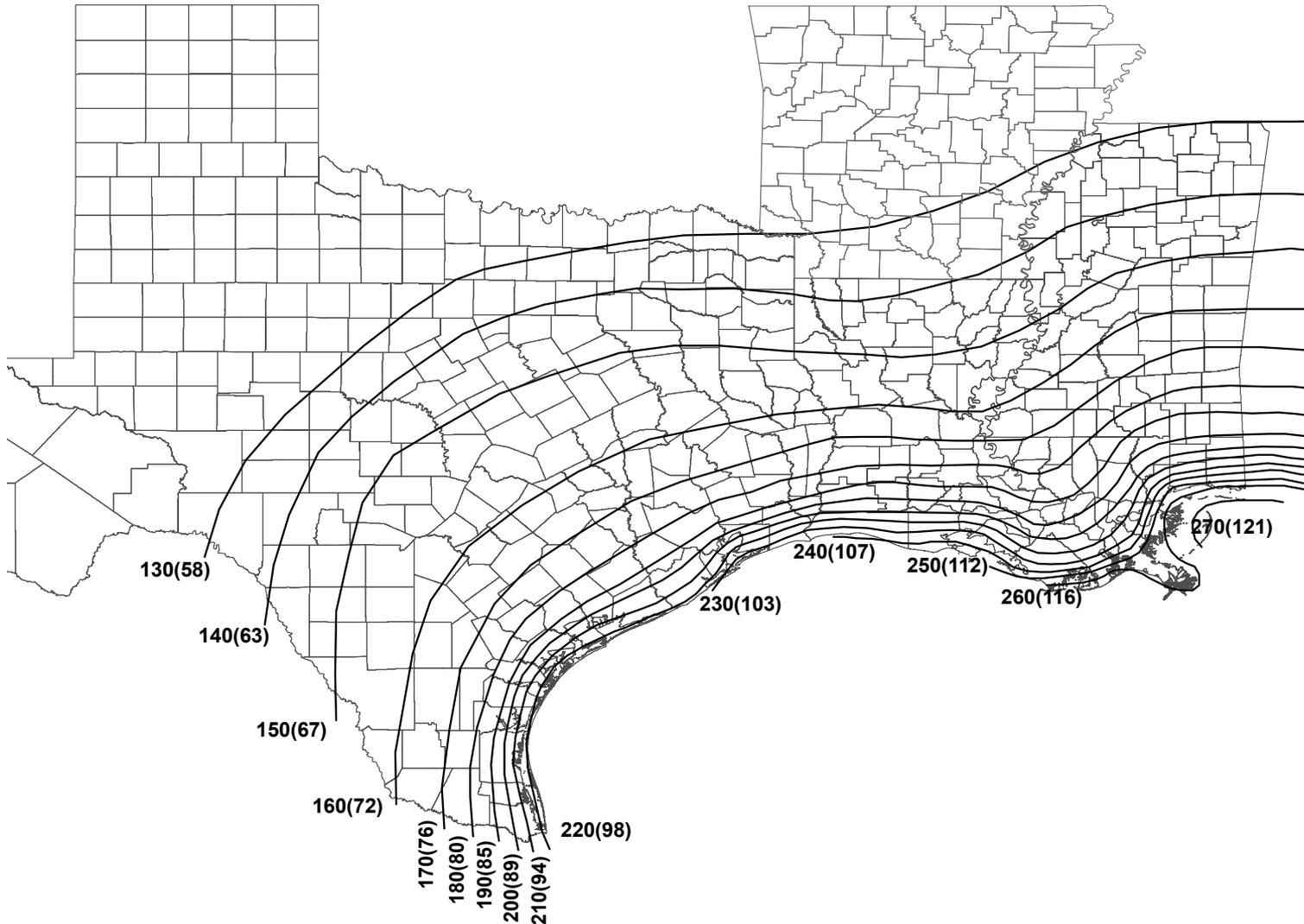
Results: NRC Model



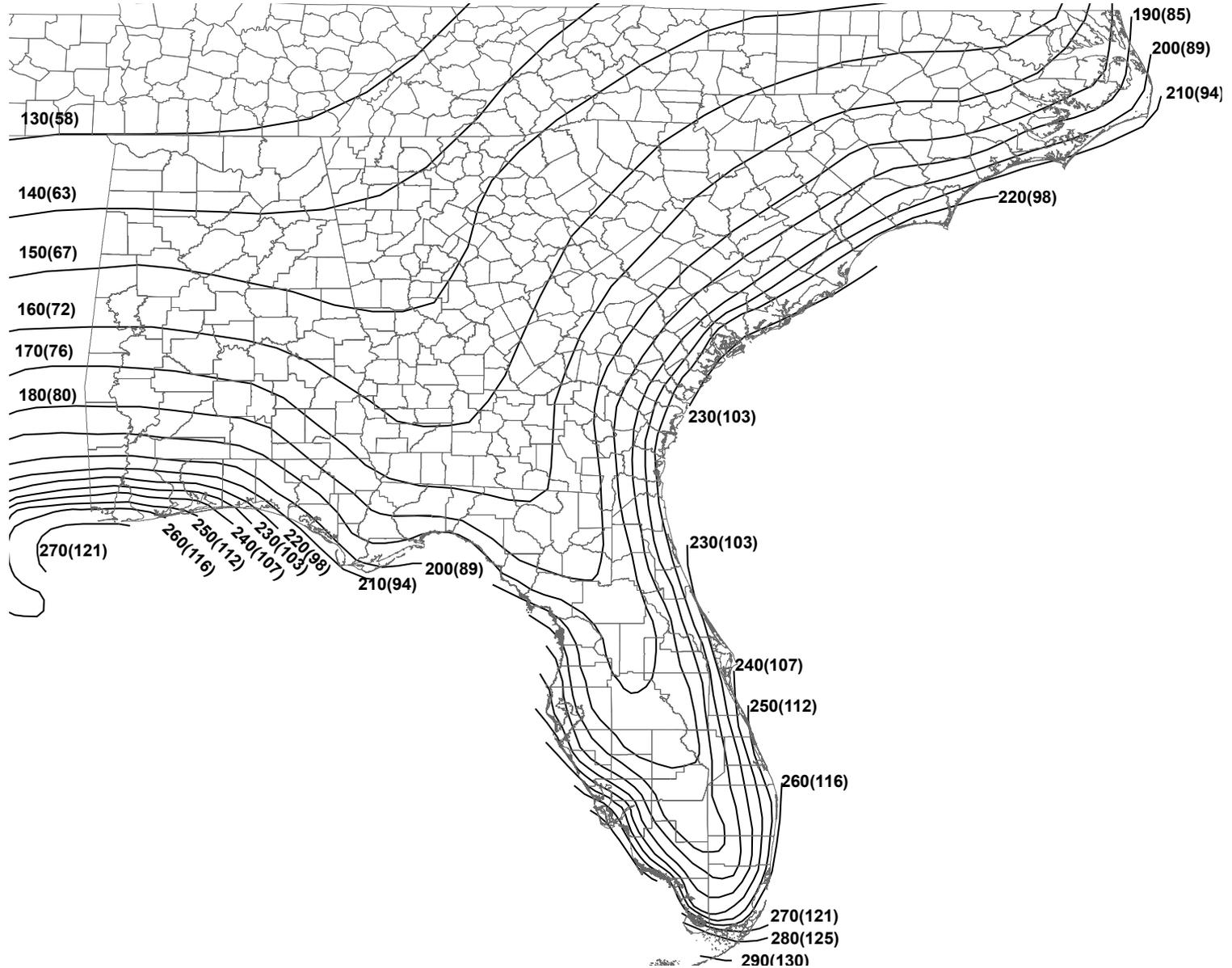
Results: Vickery et al (2009) Model



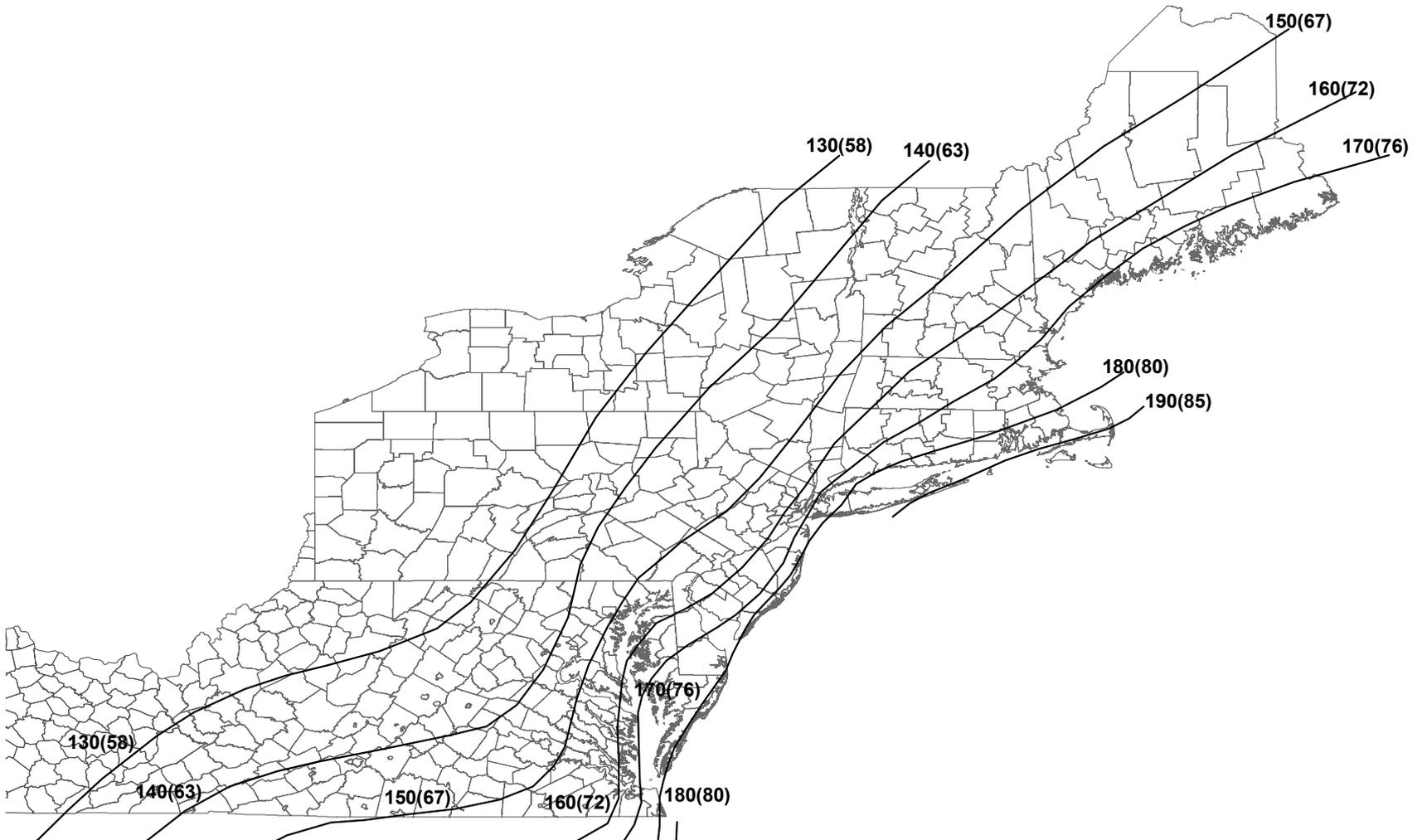
Annual Exceedance Probability: 10^{-7}



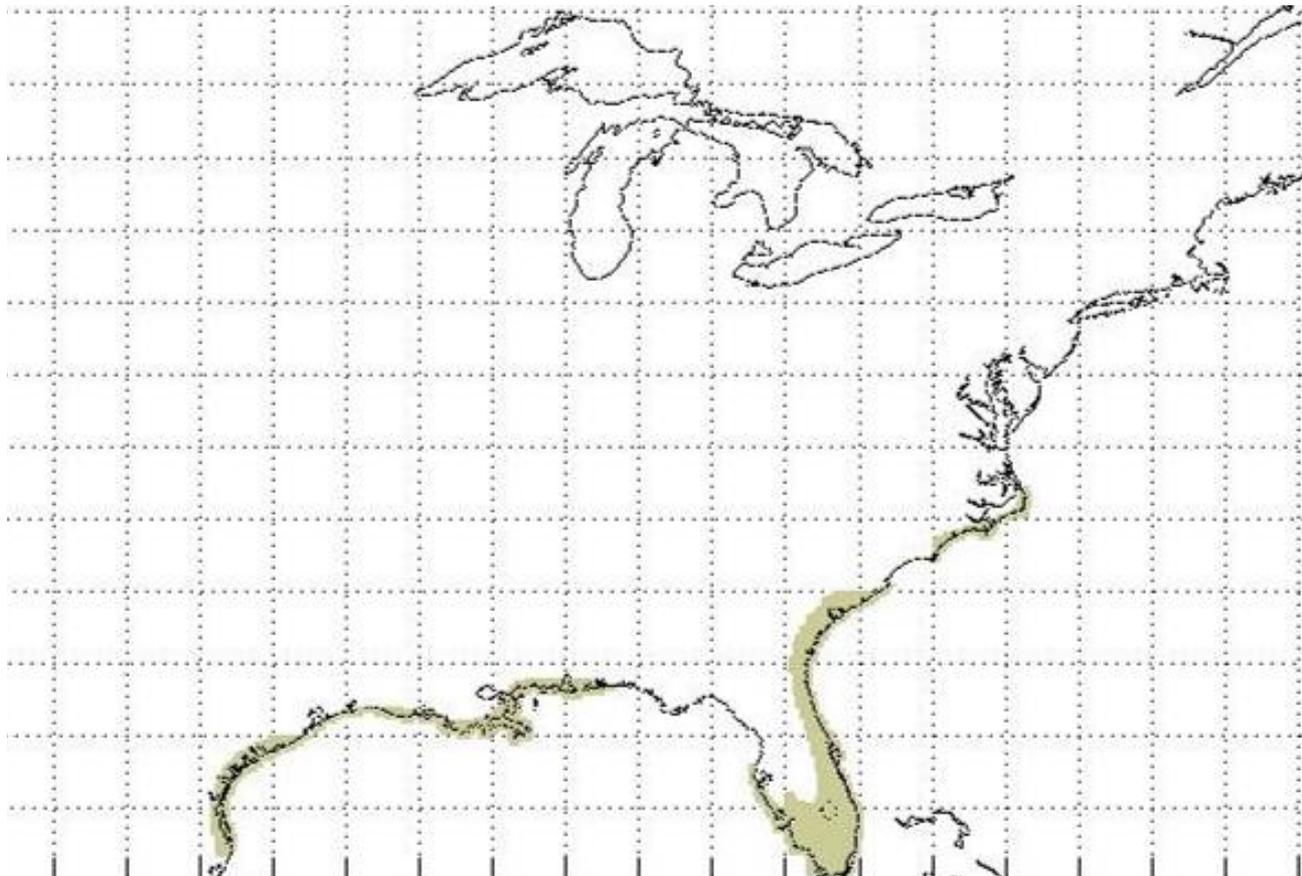
Annual Exceedance Probability: 10^{-7}



Annual Exceedance Probability: 10^{-7}



Locations Where Design-Basis Hurricane Wind Speeds Exceed those for Tornadoes (annual exceedance probability of 10^{-7})



Summary

- Original Model
 - Hazard model developed/validated using data through 2007
 - Simple ocean mixing model limits intensity
 - New statistical models for B and RMW
 - Wind model extensively validated through comparisons of modeled and observed winds both onshore and offshore
 - Windfield model errors included in wind speed estimates
 - Peer reviewed, used to develop ASCE 7-10 design wind speeds
- NRC Model Changes and Enhancements
 - Based on model used to develop ASCE 7-10 wind speeds
 - Minimum RMW reduced to 4 km for 8 km
 - Reduced storm set/weighted sample to enable model runs
 - Mean gust factor model takes into account storm duration

Summary

- NRC Model Changes and Enhancements
 - 10^{-6} and 10^{-7} winds strongly impacted by the windfield modeling uncertainty term (gust factor variation, wind field and parameter modeling deficiencies)
 - Maximum 10^{-7} gust wind speed of ~290 mph on land (~ 1 km inland in the FL keys). Assuming a gust factor in the range of 1.7 to 1.8 this 290 mph value corresponds to a one minute sustained wind speed over water in the range of 190 to 220 mph (85 – 98 m/sec). MIT 10% exceedance probability MPI for August, September and October in the South Florida area is >90 m/sec. This comparison suggests results are reasonable.

Technical Basis for Regulatory Guidance on Design-Basis Hurricane-Borne Missile Speeds for Nuclear Power Plants (NUREG/CR-7004)

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Objective and Scope

- The report documents an approach to and results of the calculation of hurricane-borne missile speeds for the design of nuclear power plants.
- The missile spectrum, the assumptions on which the calculations are based, and the range of wind speeds being considered, were based on discussions between the authors and NRC staff.
- Four types of missiles were considered in Regulatory Guide 1.76 (RG 1.76), Revision 1, entitled "Design-Basis Tornado and Tornado Missiles for Nuclear Power Plants".
- In order to provide an adequate coverage, three more types of missiles (one plate-like missile and two plank-like missiles) were included in the missile spectrum. Such missiles arise from dislodged metallic siding attached to Non-Seismic Category buildings during a tornado event.
- It is a safety concern that those wind-borne siding missiles may compromise the structural integrity of the neighboring nuclear island Seismic Category I structures. This addition was required because the characteristics of those missiles differ significantly from those of the four types tabulated in RG 1.76, Rev. 1.

Equations of horizontal and vertical motion of missile in flow with constant velocity v_h

- Horizontal and vertical projections of Newton's second law applied to the missile embedded in the wind flow:

- $$dv_{mh}/dt = (v_h - v_{mh})\{a[(v_h - v_{mh})^2 + v_{mv}^2]^{1/2}\}$$

- $$dv_{mv}/dt = g - av_{mv}[(v_h - v_{mh})^2 + v_{mv}^2]^{1/2}$$

where $a = \frac{1}{2}\rho C_D A/m$

Basic Assumptions

1. Hurricane updraft speeds are negligible.
2. Missile starts motion with zero initial velocity from elevation h . Following Rev. 1, RG 1.76, $h = 40$ m; however, calculations for $h = 30$ m, 20 m, and 10 m were also performed.
3. Wind speeds vary with height above ground in accordance with power law for (a) open terrain and (b) suburban terrain.
4. Missile drag coefficient is independent, on average, of missile position or relative missile speed with respect to wind flow.

Missile Spectrum

- *Missile spectrum contains all missiles considered in RG 1.76:*
- $a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0043 \text{ m}^2/\text{kg} = 0.0026 \text{ m}^{-1}$ (Sch. 40 pipe)
- $a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0070 \text{ m}^2/\text{kg} = 0.0042 \text{ m}^{-1}$ (5 m x 2 m x 1.3 m automobile; tornado regions I, II)
- $a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0095 \text{ m}^2/\text{kg} = 0.0057 \text{ m}^{-1}$ (4.5 m x 1.7 m x 1.5 m automobile; tornado region III)
- $a = \frac{1}{2} \times 1.2 \text{ kg m}^{-3} \times 0.0034 \text{ m}^2/\text{kg} = 0.0021 \text{ m}^{-1}$ (Solid steel sphere, $C_D = 0.41$)

Additional missiles studied

$$(C_D = 1.2)$$

- *Steel board batten siding coated w/ PVC*
(3.05 m x 0.305 m, $m = 3.8$ kg; $a = 0.176$ m⁻¹)
- *Slab*
(3.05 m x 1.53 m, $m = 38$ kg; $a = 0.085$ m⁻¹)
- *Plank*
($A = 1$ m², $m = 9.06$ kg; $a = 0.079$ m⁻¹)

Numerical Solutions

- For all open and suburban terrain cases, equations of motion were solved numerically.

To check the accuracy of the numerical solver, the equation of motion was solved for a case where a solution in closed form could be obtained (wind speeds invariant with height). Excellent agreement was found between numerical and analytical solutions (Appendix A).

Table 1 - Terminal horizontal missile speeds - 40 m, open terrain

v_{10}	Missile Characteristic, a (m^{-1})						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	<i>Steel sph.</i>	<i>Sch.40 pipe</i>	<i>5 m autom.</i>	<i>4.5 m autom.</i>	<i>Plank</i>	<i>Slab</i>	<i>Plank</i>
40	9.9	11.7	16.6	20.1	37.9	37.5	34.8
45	12.1	14.2	19.9	24.0	42.5	42.1	38.9
50	14.4	17.0	23.4	28.0	47.1	46.6	42.9
55	17.0	19.8	27.1	32.1	51.7	51.1	46.9
60	19.6	22.9	30.9	36.4	56.2	55.5	50.8
65	22.4	26.0	34.9	40.8	60.7	59.9	54.7
70	25.4	29.3	39.0	45.3	65.1	64.2	58.5
75	28.4	32.8	43.1	49.8	69.4	68.5	62.3
80	31.6	36.3	47.4	54.4	73.8	72.7	66.0
85	34.9	39.9	51.8	59.1	78.0	76.9	69.7
90	38.3	43.7	56.2	63.9	82.3	81.0	73.3
95	41.8	47.5	60.7	68.7	86.5	85.1	76.9
100	45.3	51.4	65.2	73.6	90.6	89.2	80.4
105	49.0	55.4	69.9	78.5	94.7	93.2	83.9
110	52.7	59.4	74.5	83.4	98.8	97.1	87.3
115	56.5	63.6	79.2	88.4	102.8	101.0	90.8
120	60.4	67.7	84.0	93.4	106.7	104.9	94.2
125	64.3	72.0	88.8	98.4	110.7	108.8	97.5
130	68.3	76.3	93.6	103.5	114.6	112.6	100.8
135	72.3	80.6	98.5	108.6	118.5	116.3	104.1
140	76.4	85.0	103.4	113.7	122.3	120.1	107.4
145	80.6	89.5	108.3	118.8	126.1	123.8	110.6
150	84.8	94.0	113.2	123.9	129.9	127.5	113.9

Terminal horizontal missile speeds (in m/s) as functions of parameter a (in m^{-1}) and wind speed $v_{10} = v_h^{open}(10\text{ m})$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

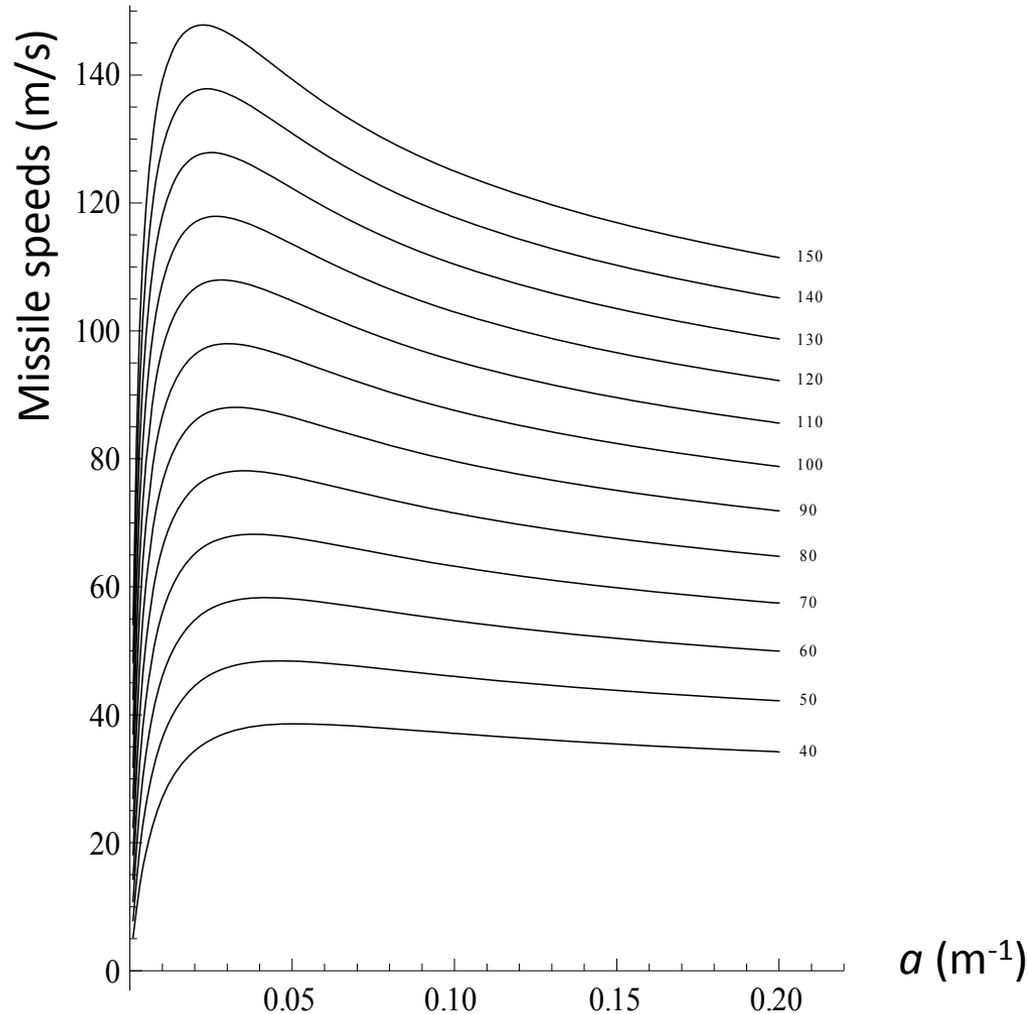
Table 2 - Terminal total missile speeds - 40 m, open terrain

V_{10}	Missile Characteristic, a (in m^{-1})						
	0.0021	0.0026	0.0042	0.0057	0.079	0.0885	0.176
	<i>Steel sph.</i>	<i>Sch.40 pipe</i>	<i>5 m autom.</i>	<i>4.5 m autom.</i>	<i>Plank</i>	<i>Slab</i>	<i>Plank</i>
40	27.7 (69)	28.1 (65)	29.5 (56)	31.0 (49)	39.3 (16)	38.8 (15)	35.4 (11)
45	28.4 (65)	29.1 (61)	31.4 (51)	33.5 (44)	43.8 (14)	43.2 (13)	39.4 (9)
50	29.4 (61)	30.4 (56)	33.6 (46)	36.4 (40)	48.2 (12)	47.6 (12)	43.4 (8)
55	30.6 (56)	31.9 (52)	36.2 (41)	39.6 (36)	52.7 (11)	51.9 (10)	47.3 (7)
60	32.0 (52)	33.8 (47)	39.0 (38)	43.1 (32)	57.1 (10)	56.3 (9)	51.2 (7)
65	33.8 (48)	35.9 (44)	42.2 (34)	46.8 (29)	61.4 (9)	60.6 (9)	55.0 (6)
70	35.7 (45)	38.3 (40)	45.5 (31)	50.7 (27)	65.8 (8)	64.8 (8)	58.8 (5)
75	37.9 (41)	40.9 (37)	49.1 (29)	54.8 (25)	70.1 (8)	69.0 (7)	62.5 (5)
80	40.2 (38)	43.7 (34)	52.9 (26)	59.0 (23)	74.3 (7)	73.2 (7)	66.2 (5)
85	42.8 (35)	46.8 (31)	56.8 (24)	63.3 (21)	78.5 (7)	77.3 (6)	69.9 (4)
90	45.5 (33)	49.9 (29)	60.8 (22)	67.8 (19)	82.7 (6)	81.4 (6)	73.5 (4)
95	48.5 (30)	53.3 (27)	64.9 (21)	72.3 (18)	86.9 (6)	85.5 (5)	77.0 (4)
100	51.5 (28)	56.7 (25)	69.2 (19)	76.9 (17)	91.0 (5)	89.5 (5)	80.5 (3)
105	54.7 (26)	60.3 (23)	73.5 (18)	81.6 (16)	95.0 (5)	93.5 (5)	84.0 (3)
110	58.0 (25)	64.1 (22)	78.0 (17)	86.4 (15)	99.1 (5)	97.4 (4)	87.5 (3)
115	61.5 (23)	67.9 (21)	82.5 (16)	91.2 (14)	103.1 (4)	101.3 (4)	90.9 (3)
120	65.0 (22)	71.8 (19)	87.0 (15)	96.0 (13)	107.0 (4)	105.2 (4)	94.2 (3)
125	68.7 (21)	75.8 (18)	91.7 (14)	100.9 (13)	110.9 (4)	109.0 (4)	97.6 (2)
130	72.4 (19)	79.9 (17)	96.3 (14)	105.8 (12)	114.8 (4)	112.8 (3)	100.9 (2)
135	76.2 (18)	84.0 (16)	101.1 (13)	110.8 (12)	118.7 (3)	116.5 (3)	104.2 (2)
140	80.1 (17)	88.2 (15)	105.8 (12)	115.8 (11)	122.5 (3)	120.3 (3)	107.5 (2)
145	84.0 (16)	92.5 (15)	110.6 (12)	120.8 (11)	126.3 (3)	124.0 (3)	110.7 (2)
150	88.1 (16)	96.8 (14)	115.5 (11)	125.9 (10)	130.0 (3)	127.6 (3)	113.9 (2)

Terminal total missile speeds (in m/s) and angles θ of incidence of the speeds with respect to the horizontal (in parentheses, in degrees) as functions of parameter a (in m^{-1}) and wind speed $v_{10} = v_h^{open}(10 \text{ m})$ (in m/s). Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Note: 1 m/s = 3.28084 ft/s, 1 m^{-1} = 0.3048 ft^{-1}

Figure 1 - Terminal horizontal missile speeds - 40 m, open terrain



Terminal horizontal missile speeds (in m/s) for parameters a between $0.001 m^{-1}$ - $0.200 m^{-1}$ and wind speeds $v_{10} = v_h^{open}(10 m) = 40, 50, \dots, 150$ m/s. Missiles start at 40 m above ground level and reach ground level; flow over open terrain.

Example Missile Speeds

- For 125 m/s [103 m/s], 3-s hurricane wind speeds at 10 m above ground in open terrain, calculated maximum horizontal missile speeds over open terrain for $h = 40$ m (20 m; 10 m) are approximately
- Solid steel sphere:
 - 64 m/s [47 m/s] (46 m/s [33 m/s]; 32 m/s [22 m/s])
- Schedule 40 pipe:
 - 72 m/s [53 m/s] (53 m/s [38 m/s]; 37 m/s [26 m/s])
- 5 m automobile, tornado Regions I and II):
 - 89 m/s [67 m/s] (69 m/s [51 m/s]; 51 m/s [37 m/s])
- 4.5 m automobile, tornado Region III):
 - 98 m/s [76 m/s] (79 m/s [59 m/s]; 60 m/s [45 m/s])

Design-basis tornado-borne missile horizontal speeds in RG 1.76

Region I -- *design-basis maximum tornado wind speed 103 m/s (230 mph)*

- 8 m/s (solid steel sphere),
- 41 m/s (Schedule 40 pipe),
- 41 m/s (5 m automobile).

Region II -- *design basis maximum tornado wind speed 89 m/s (200 mph)*

- 7 m/s (solid steel sphere)
- 34 m/s (Schedule 40 pipe)
- 34 m/s (5 m automobile).

Region III -- *design-basis maximum tornado wind speed 72 m/s (160 mph)*

- 6 m/s (solid steel sphere)
- 24 m/s (Schedule 40 pipe)
- 24 m/s (4.5 m automobile, Region III).

Conclusions

- For the seven types of missile of interest, tables are provided which list missile speeds at the time the missile reaches the ground level, for hurricane wind speeds at 10 m above ground in open terrain ranging from 40 m/s to 150 m/s in increments of 5 m/s, and for flow over (a) open terrain and (b) suburban terrain.
- Both horizontal missile speeds and total missile speeds (resultants of horizontal and vertical speeds) are listed.
- Plots showing those missile speeds as function of a parameter characterizing the missile properties are also provided. Similar tables and plots list maximum (as opposed to terminal) missile speeds.

Regulatory Guide 1.221 Public Comments

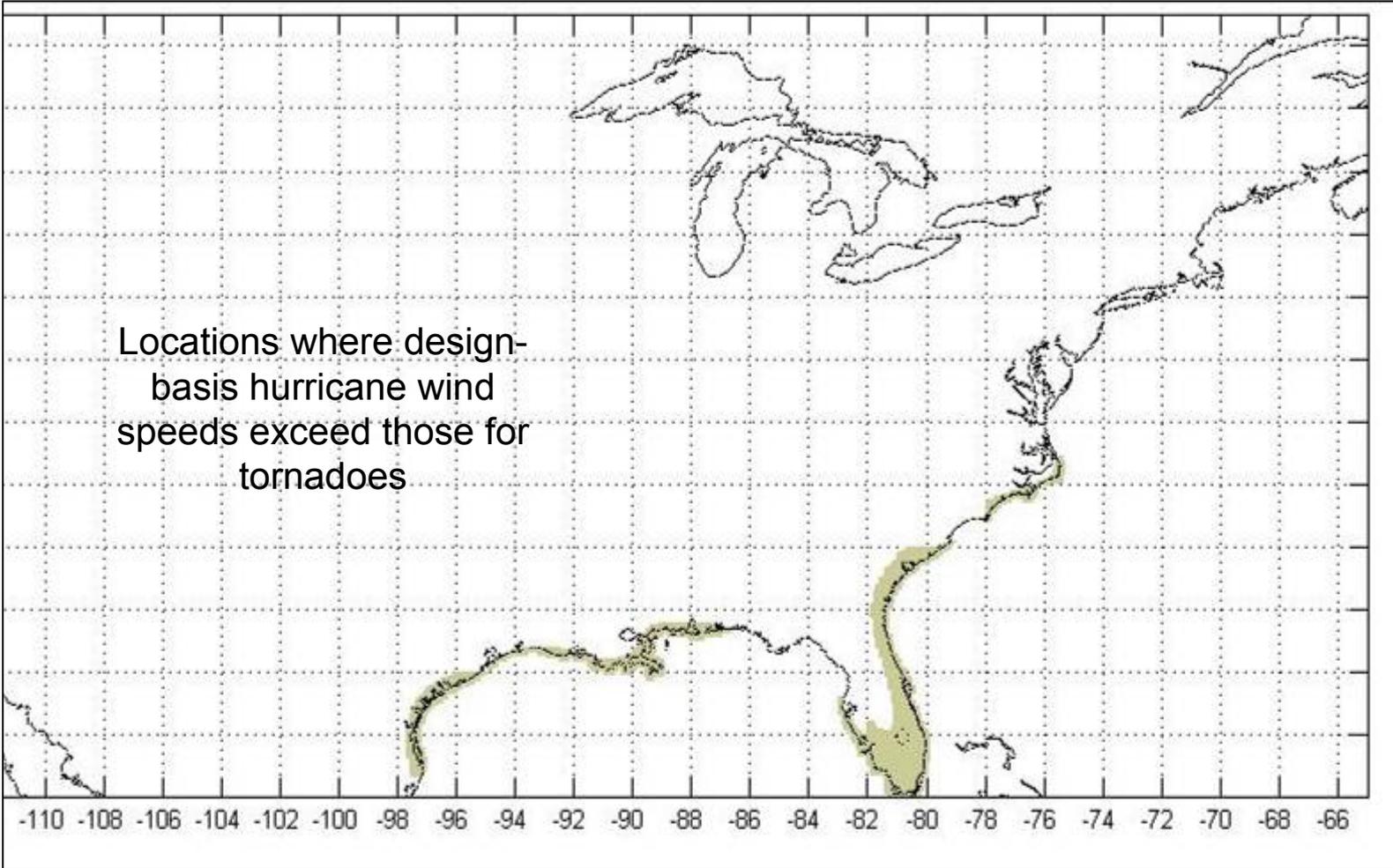
Dr. Selim Sancaktar
NRC Office of Nuclear Regulatory
Research



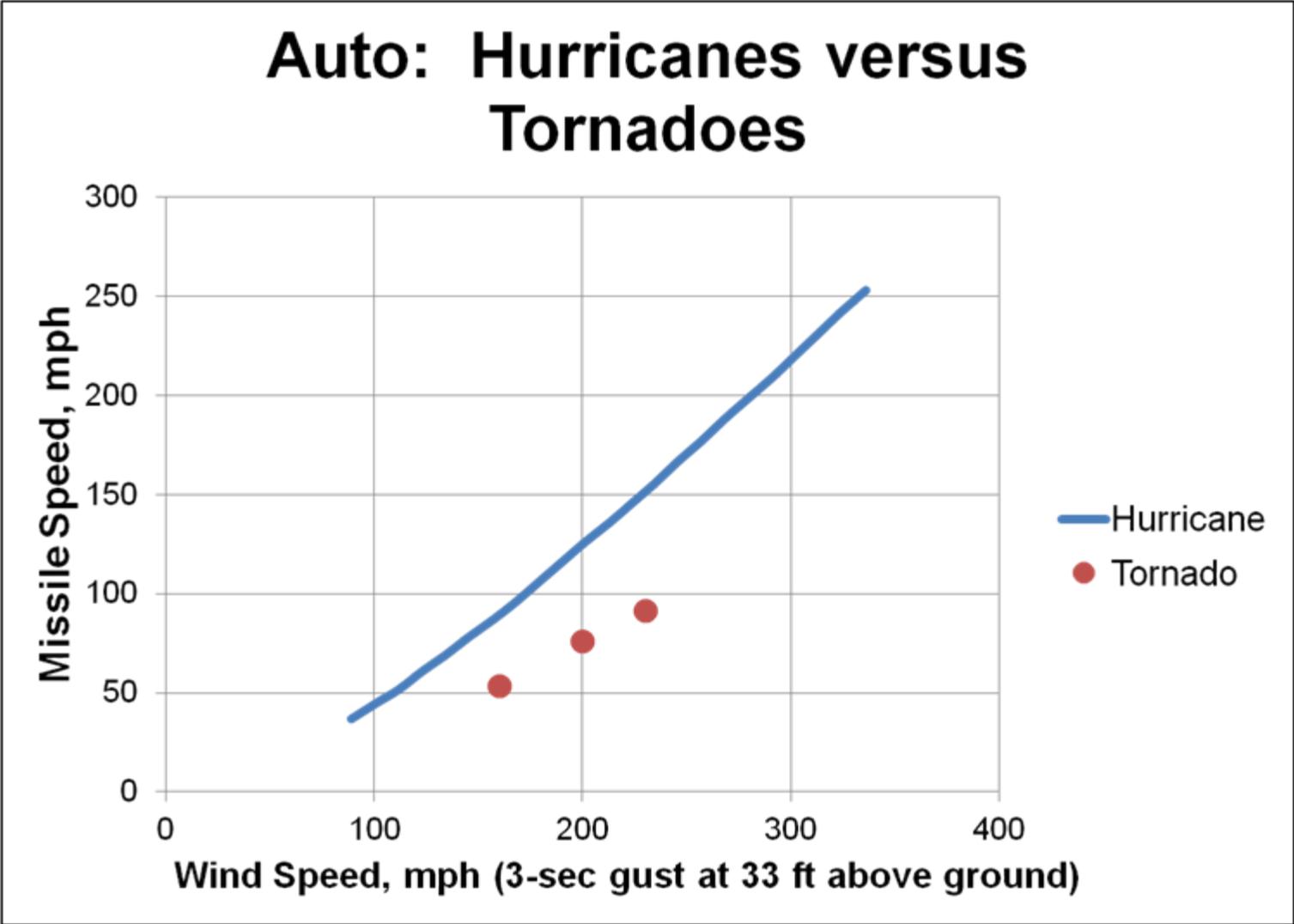
Public Comments and Conclusion

- Three comments were received after the public comment period was closed.
- The comments were addressed; none of the comments impacted the essence of the RG and the NUREG/CRs.
- Four documents are created and are ready to be declared as final (RG, two NUREG/CRs and responses to the public comments).

Design-Basis Hurricane Wind Speeds



Maximum Horizontal Missile Speeds



Maximum Horizontal Missile Speeds

- The same missile has a higher maximum velocity in a hurricane wind field than in a tornado wind field with the same maximum (3-sec gust) wind speed
 - Tornado missiles are subject to the strongest winds only at the beginning of their flights
 - Hurricane missiles are subjected to the highest wind speeds throughout their trajectory

Conclusions

- Design-basis hurricane wind speeds are higher than those for tornadoes along the coastline south of the border between North Carolina and Virginia
 - Maximum: 290 mph in the Florida keys
- Airborne missiles fly faster in a hurricane wind field as compared to a tornado wind field of the same strength

Backup Slides



Tornado Model

$$P(u \geq u_o) = P_p(u \geq u_o) + P_l(u \geq u_o)$$

Point Structure Term

$$P_p(u \geq u_o) = P_p \times P_p(u \geq u_o | s)$$

$$P_p = A_t / (N A_r)$$

$$P_p(u \geq u_o | s) = A_{u \geq u_o} / A_t$$

Large Structure Term

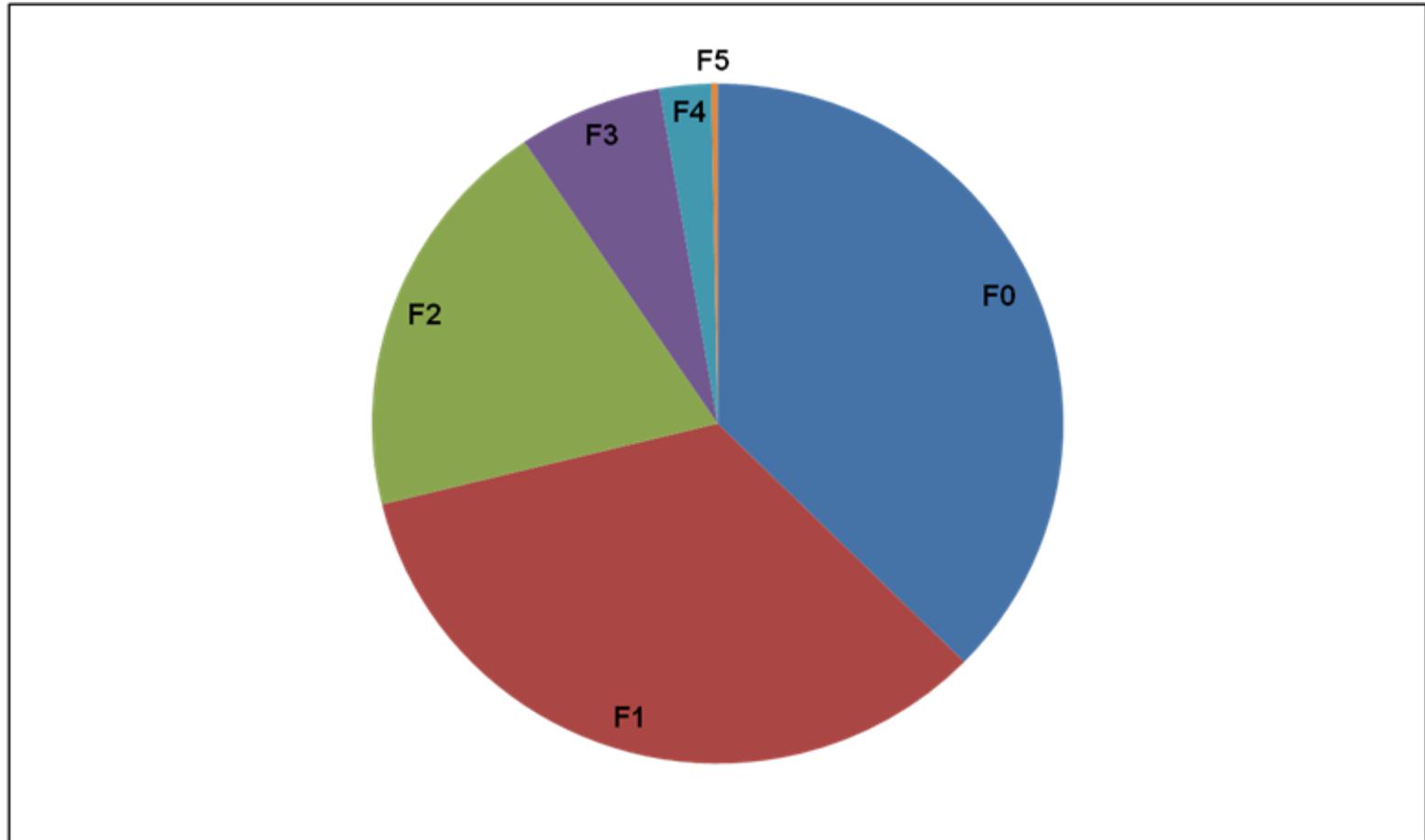
$$P_l(u \geq u_o) = P_l \times P_l(u \geq u_o | s)$$

$$P_l = A_t / (N A_r) = (w_s L_t) / (N A_r)$$

$$P_l(u \geq u_o | s) = L_{u \geq u_o} / L_t$$

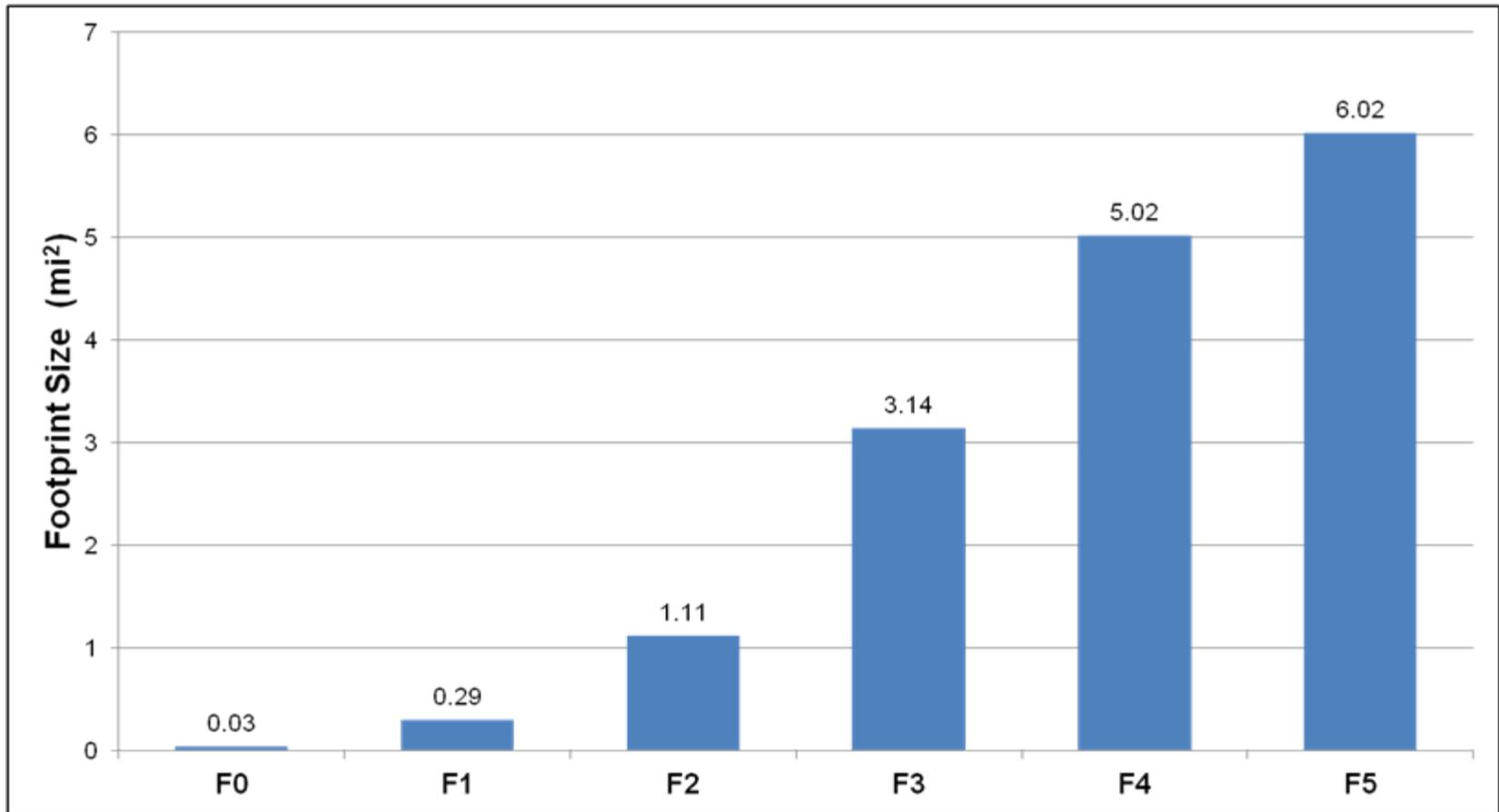
Frequency of Reported Tornado Intensities

Jan 1950 - Aug 2003



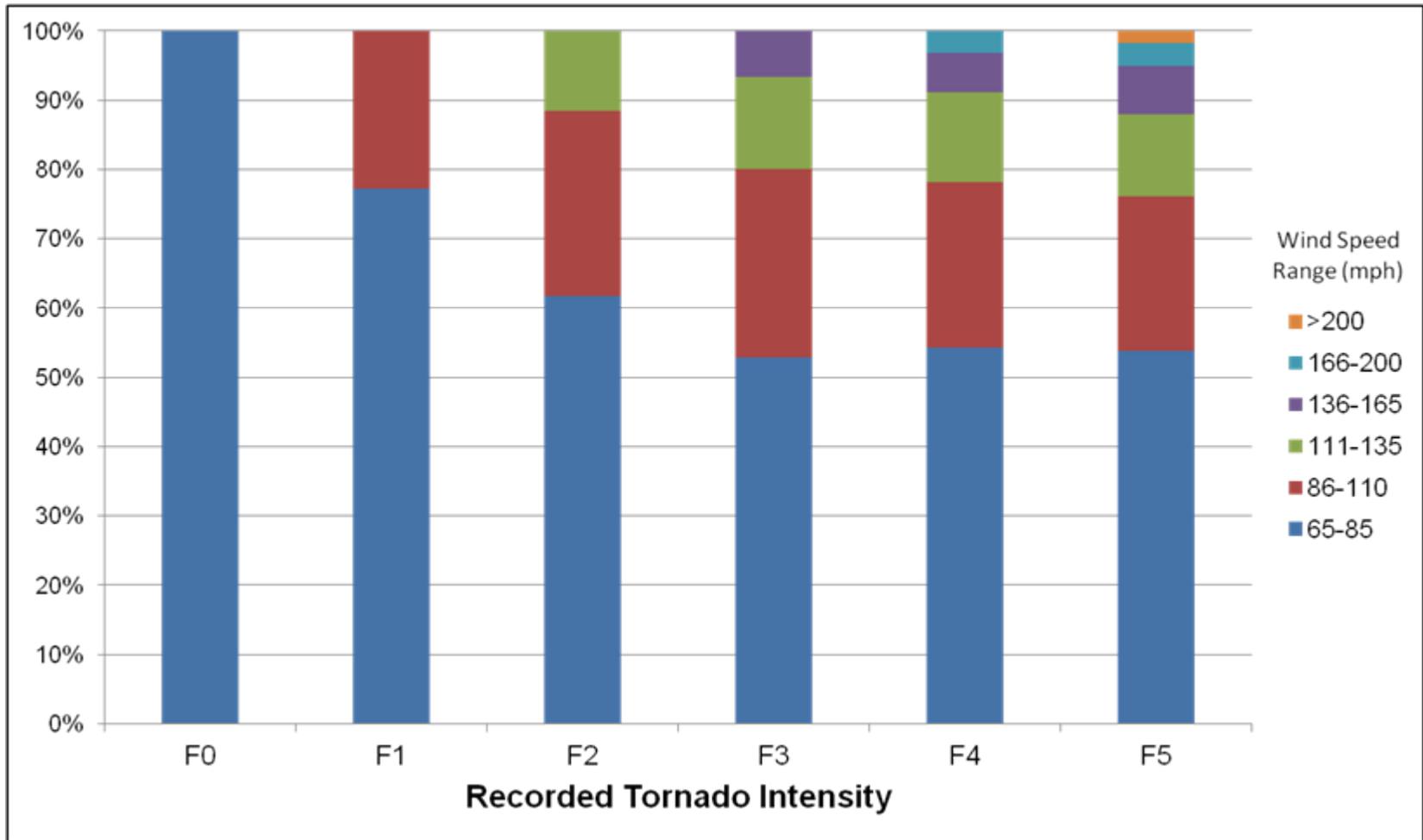
Size of US Tornadoes as a Function of Reported Intensity

Jan 1950 - Aug 2003



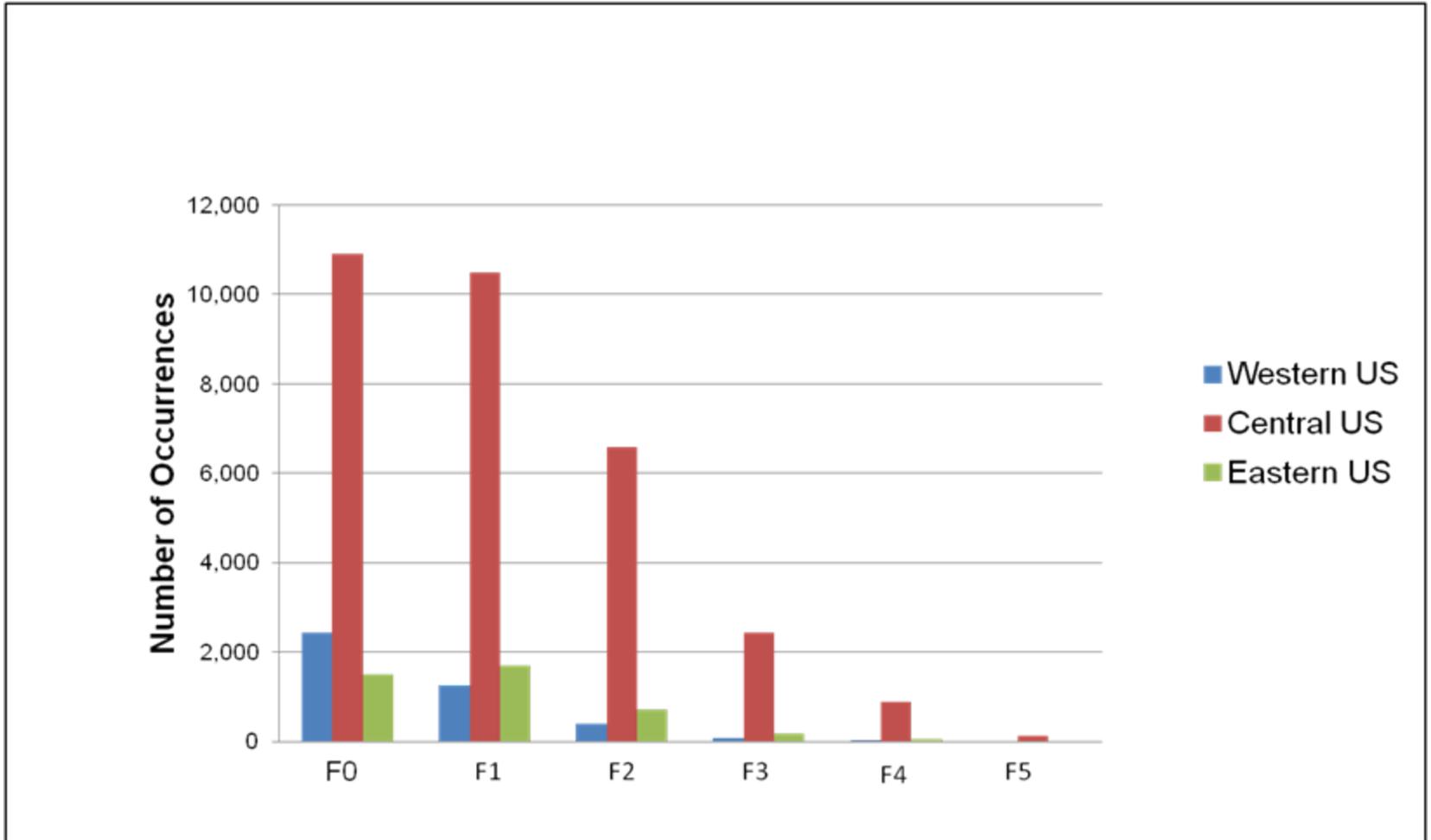


Variation of Wind Speed within the Impact Area



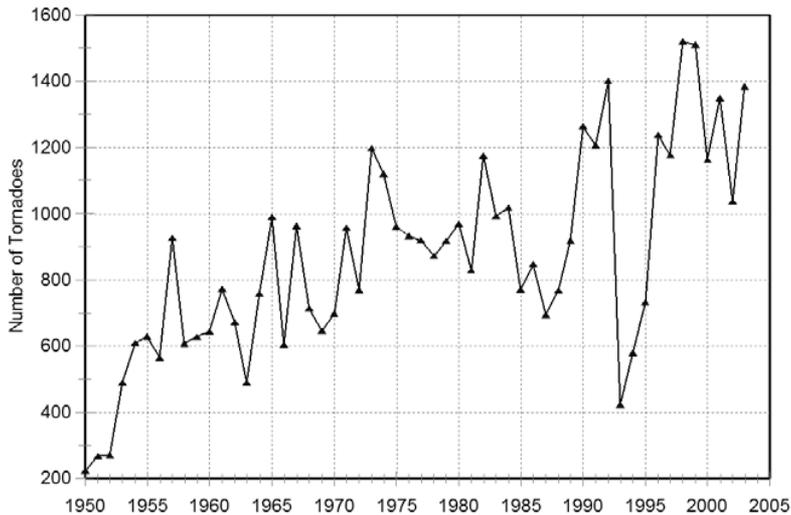
Regional Tornado Statistics

Jan 1950 - Aug 2003

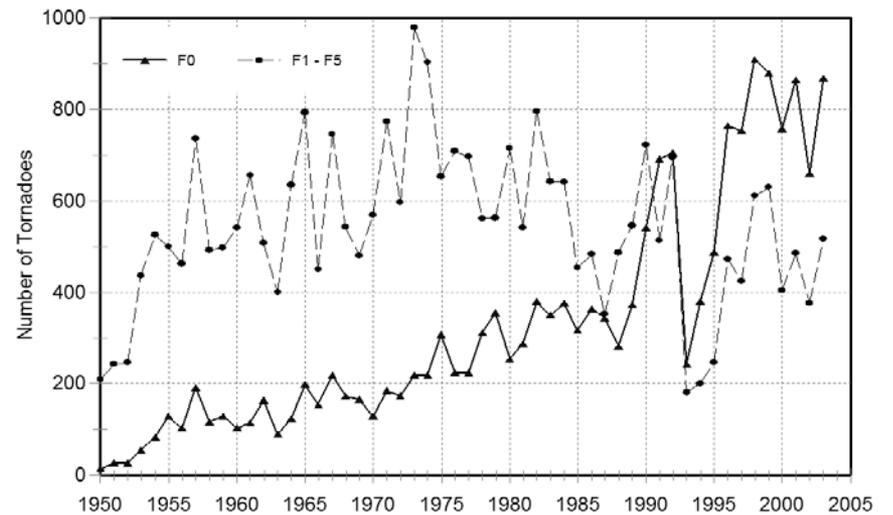


Tornado Frequency Trends

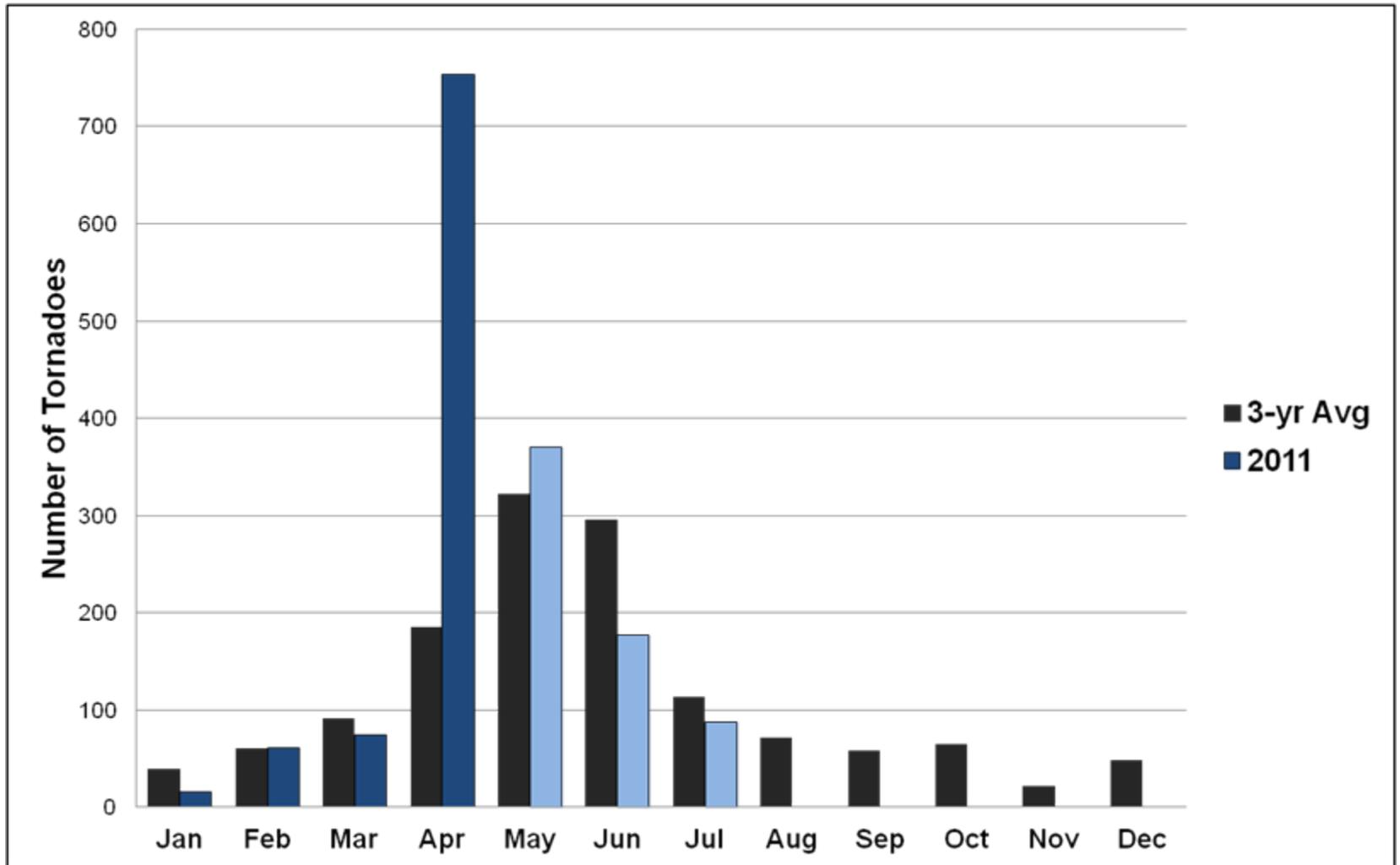
Annual Number of Reported Tornadoes (Jan 1950 - Aug 2003)



Number of F0 and F1-F5 Tornadoes (Jan 1950 - Aug 2003)



2011 Tornado Statistics

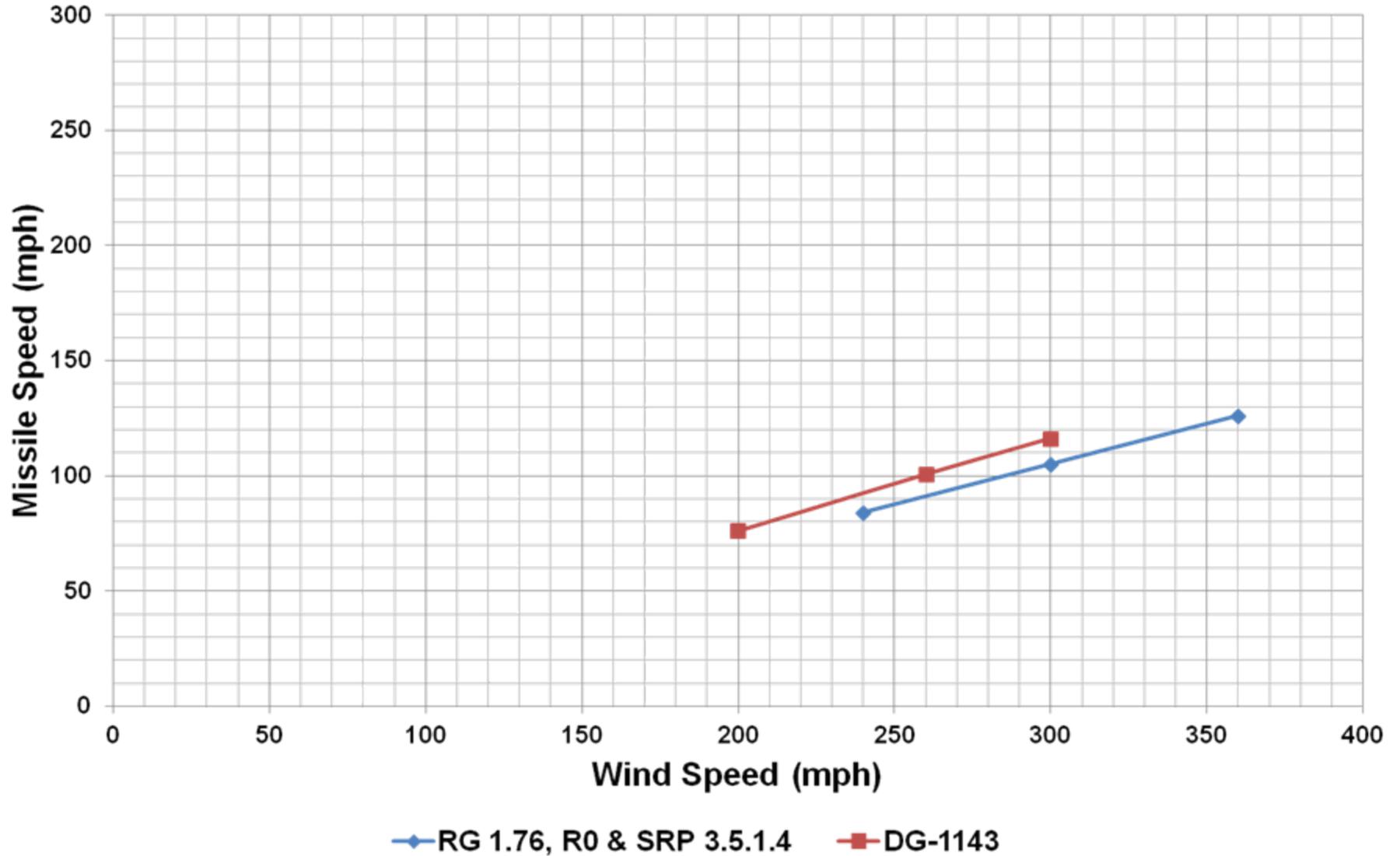




Recommended Tornado Design Wind Speeds

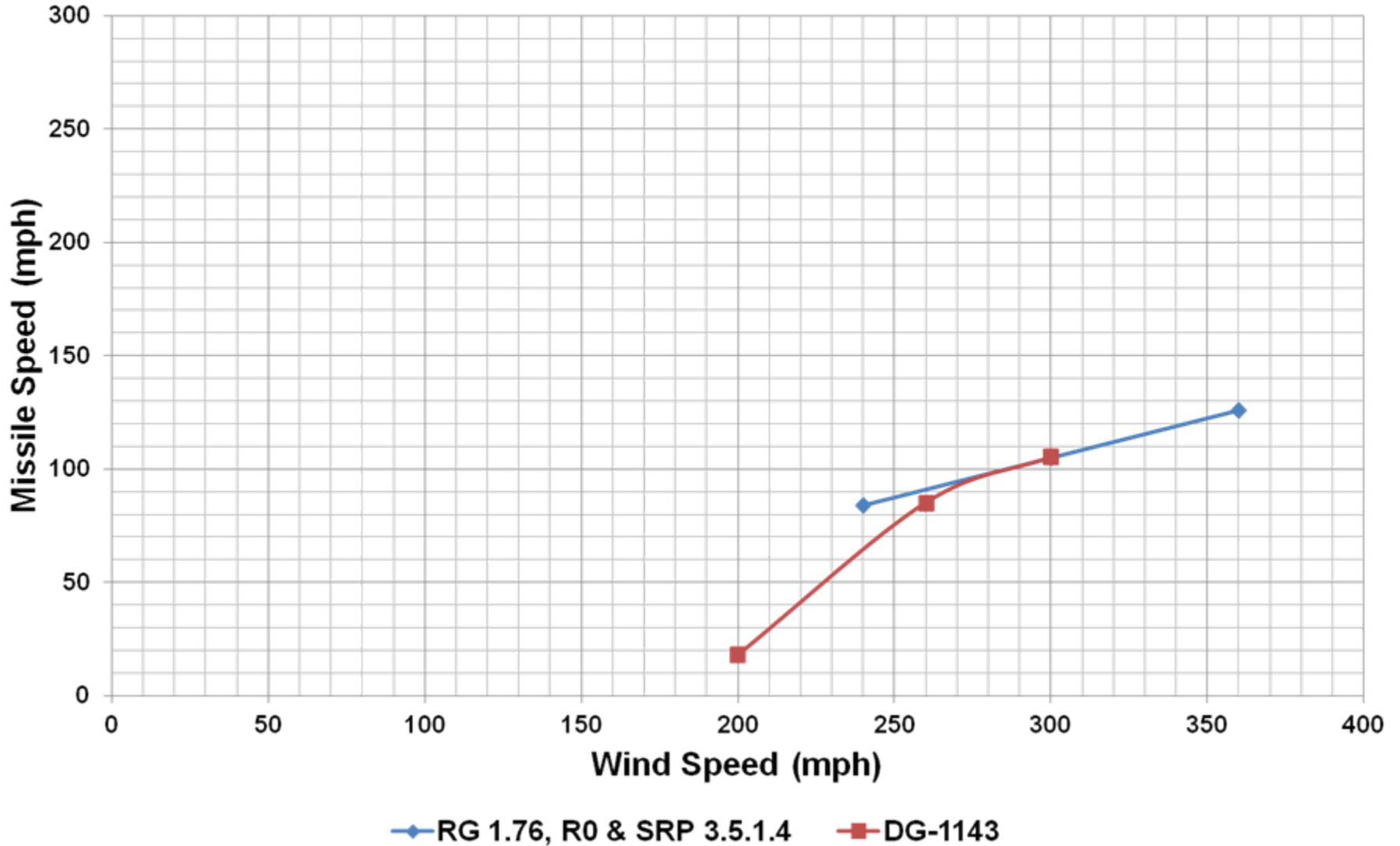
	124	122	120	118	116	114	112	110	108	106	104	102	100	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66				
47	0	144	130	158	142	91	103	159	168	164	198	180	199	186	186	183	213	195	169										191					
45	117	138	127	148	137	107	124	132	150	154	177	194	200	204	205	212	217	213	212	208	183	210						95	166	179				
43	84	119	113	71	148	114	147	148	151	162	186	197	201	211	216	221	223	222	220	215	212	215		184	203	176	179	169	172	170				
41	133	0	100	0	0	123	146	137	132	158	177	198	207	219	225	225	228	230	223	226	225	220	221	222	204	197	201	200						
39	152	151	130	148	83	146	125	142	123	120	177	191	210	223	229	230	225	227	227	226	225	215	202	203	200	202	172							
37		162	142	81	0	108	130	117	125	151	161	192	215	225	232	229	220	219	224	223	218	205	189	194	201	194								
35		159	134	140	0	138	142	124	112	136	163	194	217	229	235	228	226	227	226	229	219	200	208	206	193	195								
33			76	160	153	140	141	148	72	144	164	198	212	221	226	227	227	226	228	228	219	213	207	214	188									
31					135	140	142	148	145	151	161	187	200	207	214	222	221	223	224	219	215	210	195	193										
29	Region 1 -- 230 mph											123	182	183	200	208	211	211	204	211	205	203	198	199										
27	Region 2 -- 200 mph														203	186	196	173							212	198								
25	Region 3 -- 160 mph															181	192								227	191								

Massive Missile Speeds

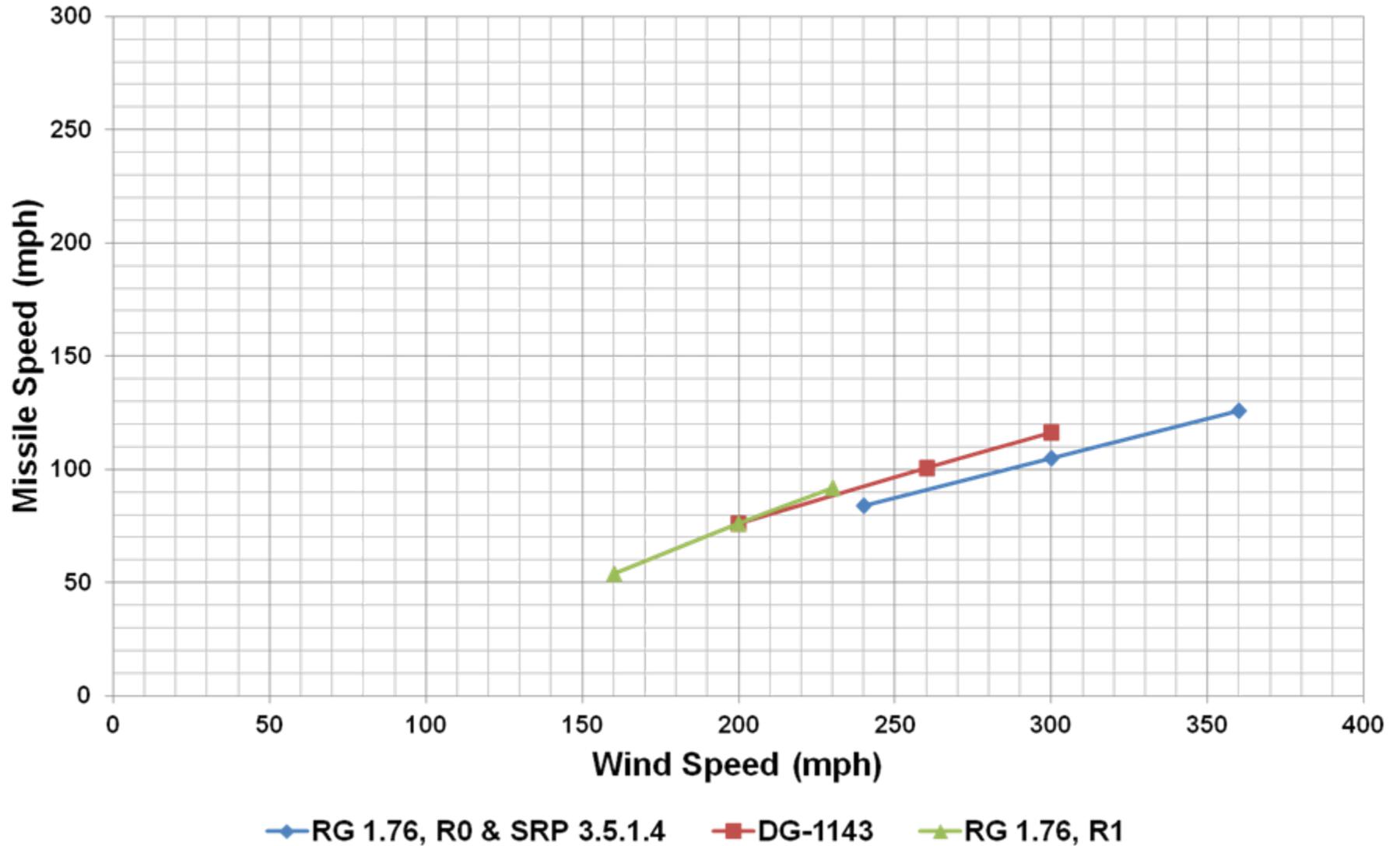




Rigid Missile Speeds

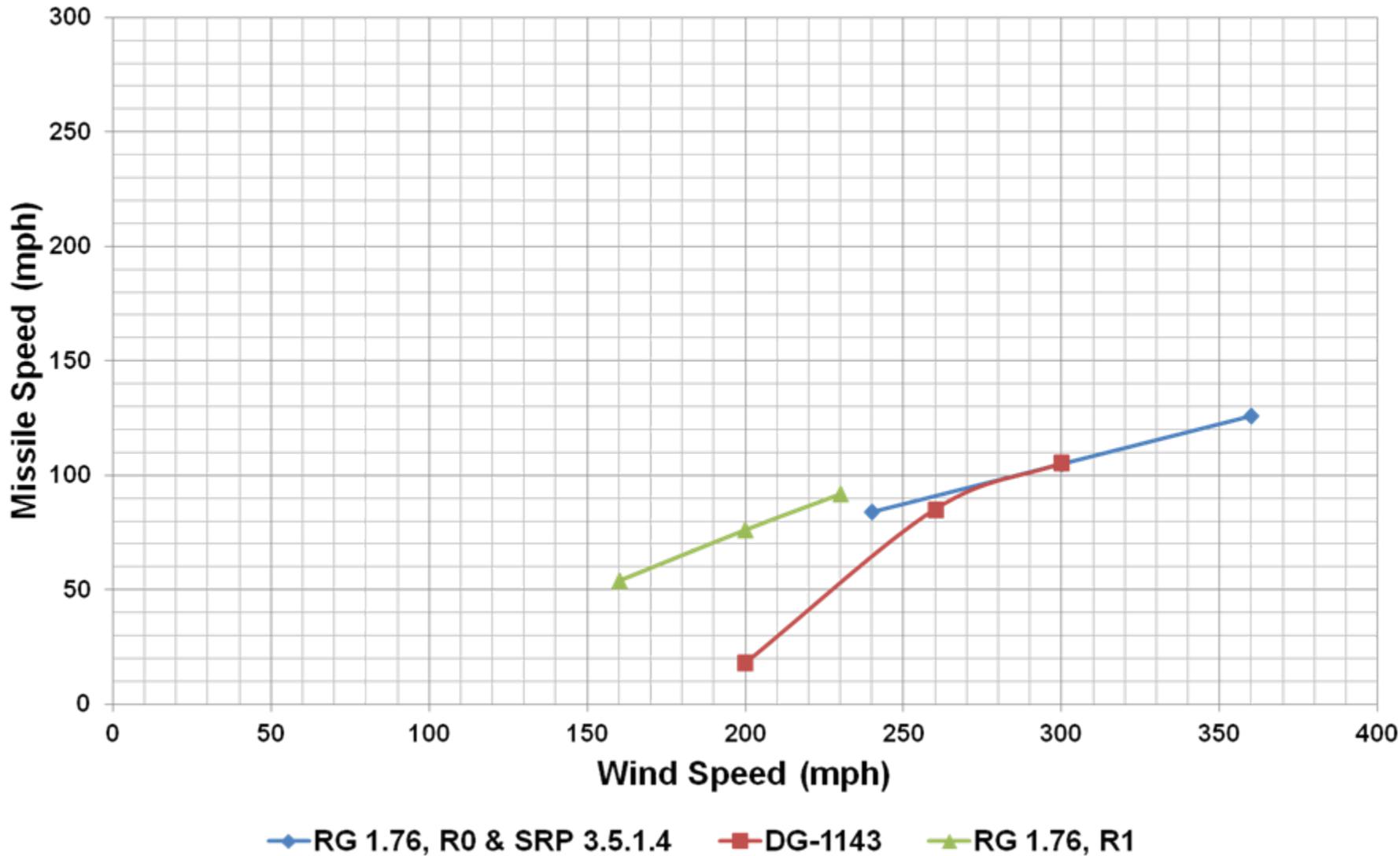


Massive Missile Speeds

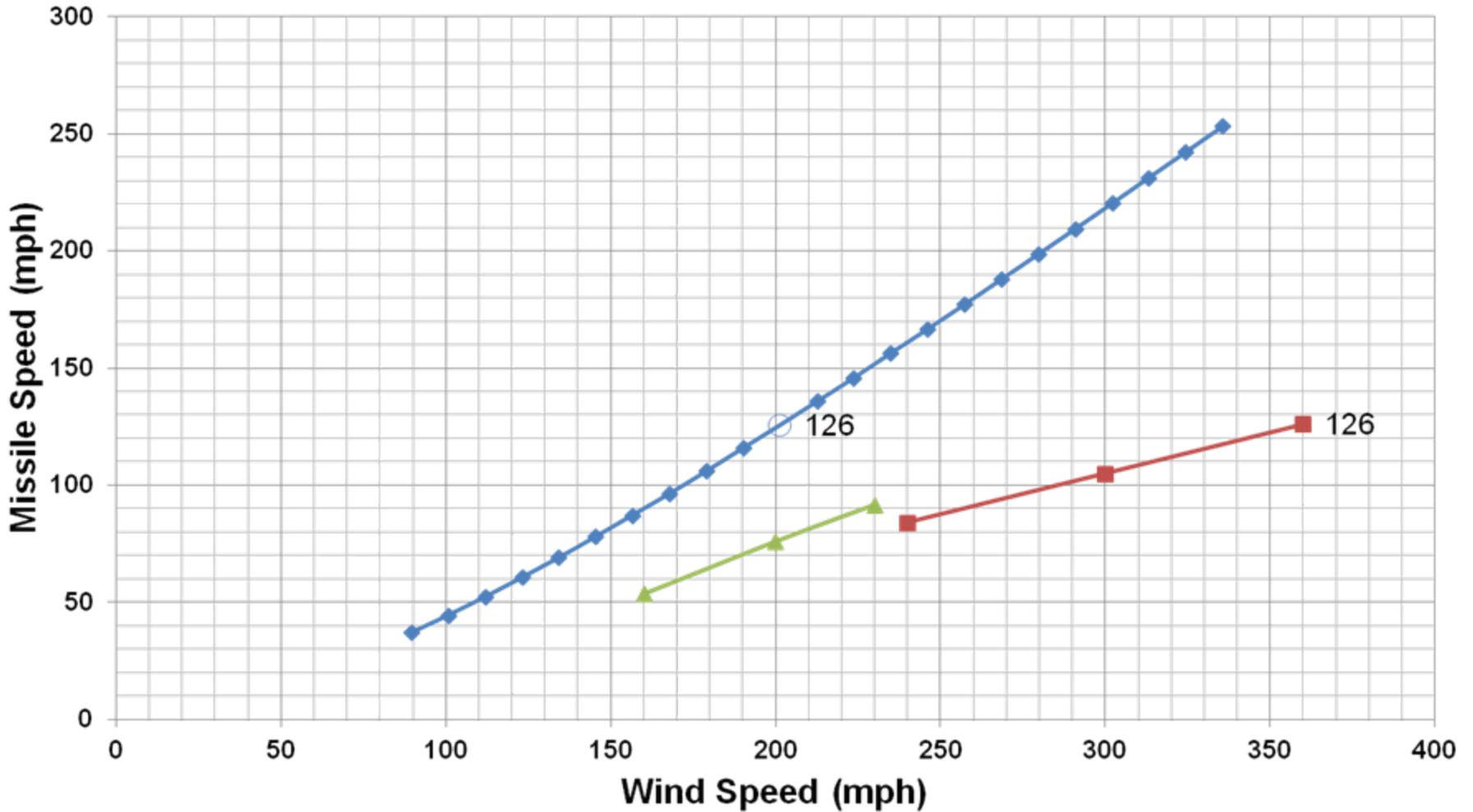




Rigid Missile Speeds

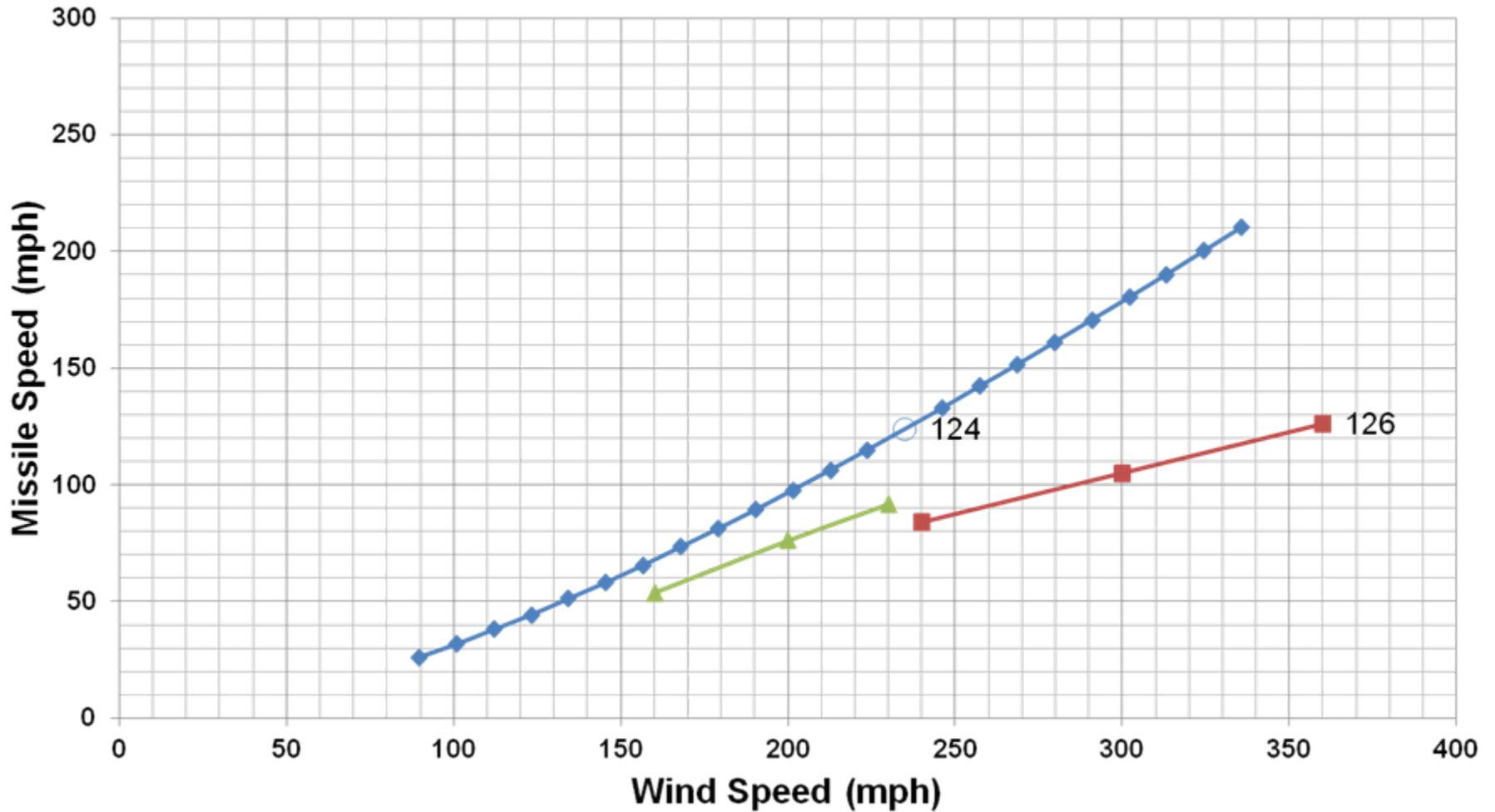


Massive Missile Speeds



—◆— RG 1.221 —■— RG 1.76, R0 & SRP 3.5.1.4 —▲— RG 1.76, R1

Rigid Missile Speeds



RG 1.221

RG 1.76, R0 & SRP 3.5.1.4

RG 1.76, R1